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STUDY OF AIRCRAFT IN INTRAURBAN TRANSPORTATION SYSTEMS

Final Report

VOLUME 2

JUNE 1971

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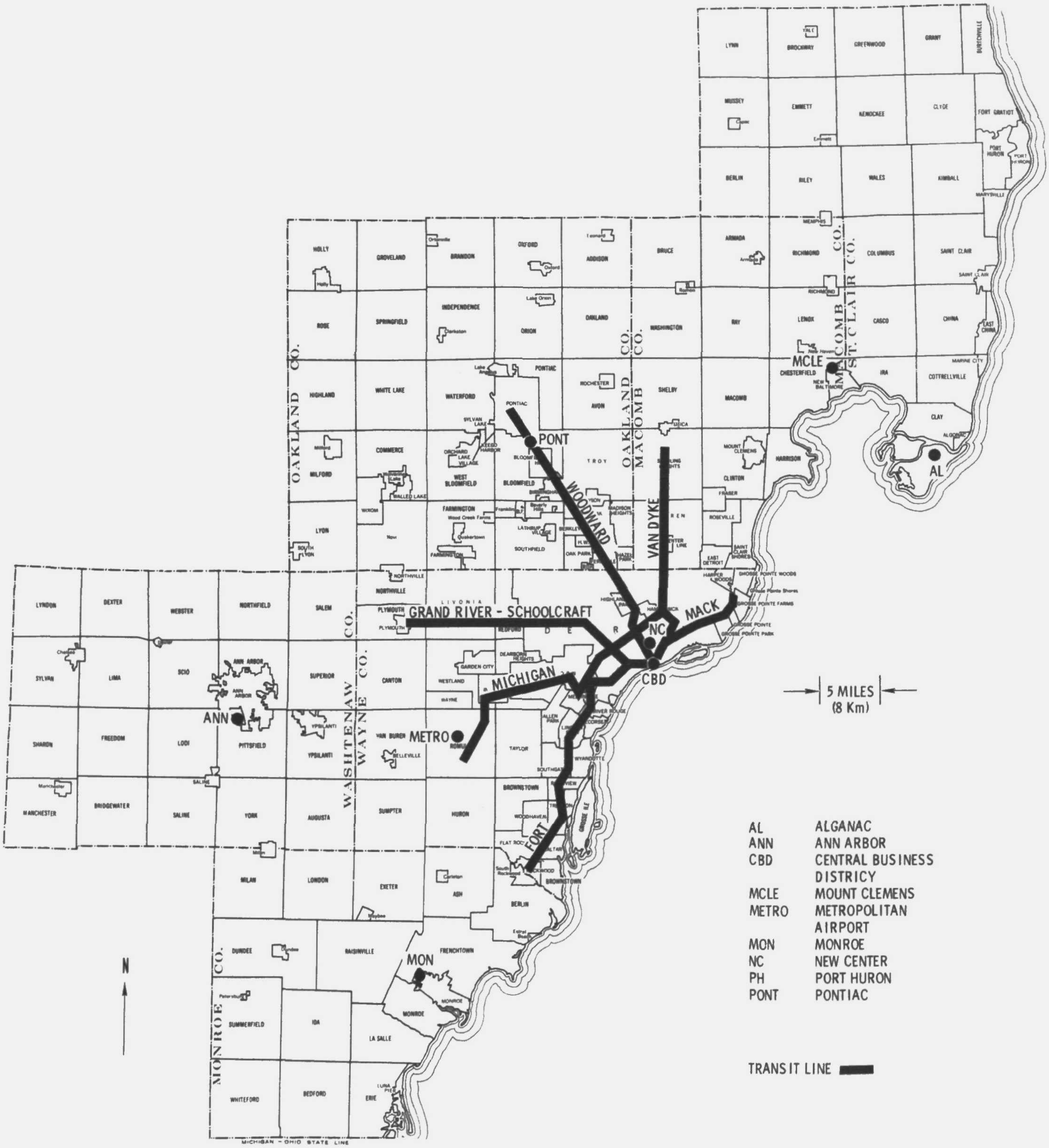
for
AMES RESEARCH CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

LOCKHEED-CALIFORNIA COMPANY • BURBANK
A DIVISION OF LOCKHEED AIRCRAFT CORPORATION



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FOREWORD

The Study of Aircraft in Intraurban Transportation Systems was conducted under NASA Ames Research Center Contract NAS2-5989. This final report, consisting of four volumes, is submitted in compliance with the requirements of Article IV, Paragraph B-5.0 and presents all of the work accomplished by the Lockheed-California Company during the two-phase study program. This program was initiated in June 1970 and completed in May 1971.

This report is prepared within the framework of the Preliminary Final Report Outline submitted to NASA by Lockheed's letter LAC/01695, dated 26 June 1970, with minor revisions. The report contains an organized and edited version of the work reported in the previously submitted nine Monthly Progress Reports (LR 23820-1 through LR 23820-9) and the formal Phase I Oral Presentation held on 3 December 1970 at the NASA Ames Research Center facility.

This final report is subdivided into four volumes for ease in handling by the reader. Phase I - Aircraft Concepts Selection is contained in Volumes 1 and 2 (CR 114340 and CR 114341). Phase II - Aircraft Concepts Evaluation is presented in Volume 3 (CR 114342). All backup data leading to the summarized conclusions within the main body of the report are to be found in Volume 4 (CR 114343) Appendix. Each figure and table in Volume 4 is identified by the number of the section in the main body of the report that utilizes the basic data. The summary and introduction are presented in Volume 1 and the reference list is shown in Volume 3.

This study was accomplished by the Advanced Design Division, Science and Engineering Branch of the Lockheed-California Company, under the direction of the Engineering Study Manager, E. G. Stout. The principal investigators were P. H. Kesling, H. C. Matteson, D. E. Sherwood, W. R. Tuck, Jr., and L. A. Vaughn.

The work reported herein was administered under the direction of George C. Kenyon, Advanced Concepts and Missions Division, Office of Advanced Research and Technology, NASA Ames Research Center, who was designated the Technical Monitor for the contract.

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1.2 PARAMETRIC DATA DEVELOPMENT

1.2.1 AIRCRAFT SYNTHESIS METHODOLOGY

The basic initial design task is to determine an overall aircraft configuration that will meet the performance requirements. This is accomplished by doing parametric studies of each of the approach concepts. A parametric study implies creating a mathematical model of the system of concern and then varying the principal variables to obtain a spectrum of results. The Advanced System Synthesis and Evaluation Technique (ASSET) program is the basic tool employed in doing the parametric study of these aircraft systems.

The ASSET program is shown schematically in Figure 1.2-1. The program consists of six basic subroutines; i.e., configuration geometry, performance, weight sizing, research and development cost, production cost, and the direct operating cost model. Basic input data to the program includes weight and volume coefficients, performance characteristics, and costing coefficients.

An initial guess at the takeoff gross weight, wing area and fuel required is used to initiate the iteration process of the ASSET program.

The fuel consumption and flight times are computed in the performance subroutine based on the particular parametric values of thrust-to-weight ratio and wing loading being computed. These data are then fed to the weight-sizing and DOC model. Based on the assumed takeoff gross weight, each of the weight components are computed. These component elements are added together to get the calculated takeoff gross weight. The calculated takeoff gross weight is compared to the assumed weight and if they agree, this is a solution. If they do not agree, then a convergence technique is used to select the new guess and the program iterates until a convergence is found. The weight breakdown from the final iteration is then fed to print out and the costing models. An example of the weight-sizing printout is shown in Figure 1.2-2. In addition to showing the detailed weight breakdown of the major component elements, the percentage fraction of major components is shown in the right hand column.

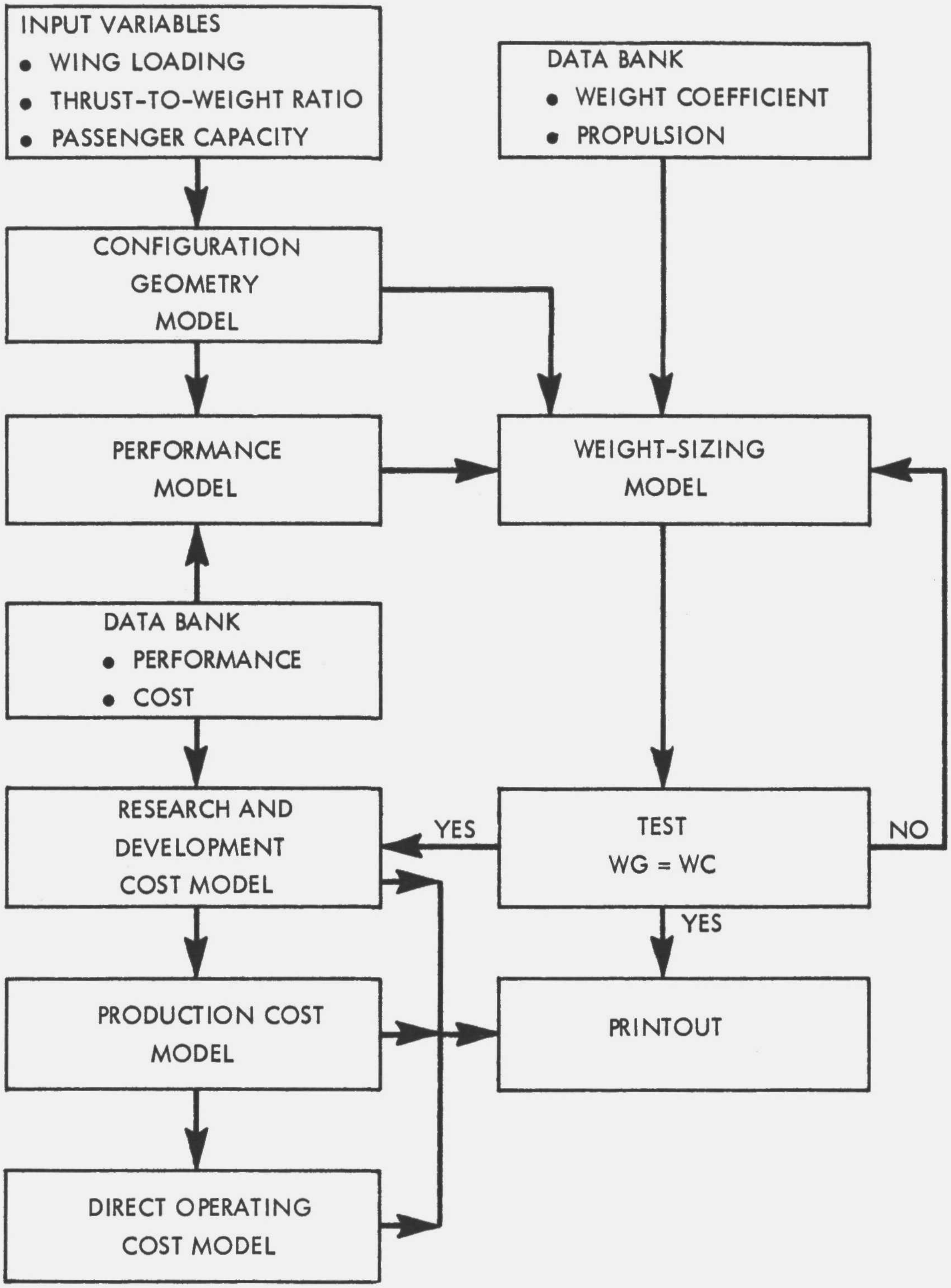

Figure 1.2-1. ASSET Schematic

DEFLECTED SLIPSTREAM STOL - 75 CASE NO. 53

DESIGN GROSS WEIGHT		42566.	
FUEL		4118.	9.67
ZERO FUEL WEIGHT		38448.	
PAYLOAD		11400.	26.78
OPERATING WEIGHT EMPTY		27048.	
OPERATIONAL ITEMS	425.		1.00
STANDARD ITEMS	107.		0.25
EMPTY WEIGHT-MFG.		26516.	
WING	3336.		7.84
TAIL	1336.		3.14
BODY	4777.		11.22
LANDING GEAR	1798.		4.22
SURFACE CONTROLS	1020.		2.40
NACELLES	836.		1.96
PROPULSION SYSTEM		4927.	11.58
ENGINE	1565.		
PROPELLERS	1615.		
FIRE EXTING.	53.		
EXHAUST	244.		
WATER INJECTION	0.		
COOLING	0.		
OIL SYSTEM (LESS OIL)	122.		
ENGINE CONTROLS	239.		
ENGINE STARTING	38.		
FUEL	433.		
INSTRUMENTS		412.	0.97
HYDRAULICS		359.	0.84
ELECTRICAL		1425.	3.35
ELECTRONICS		1178.	2.77
FURNISHINGS		3100.	7.28
AIR CONDITIONING		1422.	3.34
ANTI-ICING		241.	0.57
AUXILIARY POWER UNIT		350.	0.82
SYSTEM INTEGRATION			100.00

NO. OF PASSENGERS	60.
SEAT PITCH	32.
FUSELAGE LENGTH FT.	82.
FUSELAGE DIAMETER FT.	11.
WING AREA FT. SQ.	709.
ASPECT RATIO	7.
WING SWEEP	0.
NO. OF CREW	2.
THRUST PER ENGINE	5584.
HORIZ. TAIL AREA FT. SQ.	248.
VERT. TAIL AREA FT. SQ.	173.
WING T PEC C	18.
LANDING FIELD LENGTH FT.	0.
TAKEOFF FIELD LENGTH FT.	1374.
THRUST TO WEIGHT RATIO	0.52
WING LOADING	60.
FUEL FRACTION	0.0968

Figure 1.2-2. Weight-Sizing Printout

Figure 1.2-3 is an example of the cost printout. The cost printout represents the average cost of one aircraft of some given fleet size. This cost summary print gives the research and development cost allocation to this one aircraft. The cost of production for each of the major component elements and the total flyaway cost is shown. A detailed breakdown of the makeup of the DOC in dollars/mile is shown for the basic design mission, with the percentage makeup printout in the column to the right of the DOC's. In the lower right-hand corner, the effect of different stage lengths on DOC (cents/seat mile), block time (TB), and block speed (VB) is shown. The total acquisition cost for a given number of aircraft and the 10-year direct operations cost for a given utilization rate is printout on the bottom line as Total Fleet Operating Cost in millions of dollars.

Using this program, a series of computer runs is made to investigate the effect of wing loading, thrust-to-weight ratio, and passenger capacity on the takeoff gross weight, flyaway cost and DOC.

1.2.1.1 Parametric Data

A 60-passenger aircraft for each approach concept is selected as the initial baseline configuration. These preliminary baseline configurations provide a basis for study by each of the technology analysts, namely, aerodynamics, weights, propulsion and cost. These general arrangements of the aircraft enable the analysts to provide parametric data information on the propulsion systems, performance capabilities, fuel requirements, component weight coefficients and system cost factors.

Because of the existence of a bank of design data accumulated over the years by Lockheed, NASA and other agencies, the technologists need only focus on analyzing the unique demands of each of the given approaches.

Paragraph 1.1.2 describes the parametric data bank and shows examples of the propulsion, performance, weight and cost data for each of the different design approaches.

1.2.1.2 Performance Analysis

The takeoff and landing field length requirements for each of the approach concepts as a function of wing loading and thrust-to-weight ratio

COST SUMMARY

WING		122117.69		
TAIL		28861.16		
BODY		190821.69		
LANDING GEAR		16969.59		
FLIGHT CONTROLS		60929.16		
NACELLES		57518.30		
PROPULSION				
ENGINE	2528.25			
AIR INDUCTION	0.0			
FUEL SYSTEM	16558.86			
START SYSTEM	1507.40			
ENGINE CONTROLS	8661.46			
FIRE EXTINGUISHING	0.0			
EXH/THRUST REV.	16264.72			
LUBE SYSTEM	4671.36			
PROPELLERS	26460.86			
TOTAL PROPULSION		76652.88		
INSTRUMENTS		53169.83		
HYDRAULICS		21215.96		
ELECTRICAL		58453.33		
ELECTRONIC RACKS		12684.20		
FURNISHING		42702.54		
AIR CONDITIONING		57526.73		
ANTI ICING		3323.53		
APU		15845.57		
SYS. INTEGRATION		42207.73		
TOTAL EMPTY MFG. COST			883970.50	
SUSTAINING ENGINEERING			31718.60	
TECHNICAL DATA			24780.16	
PROD. TOOLING MAINT.			74262.25	
MISC.			4956.03	
ENG. CHANGE ORDER			53525.14	
QUALITY ASSURANCE			107235.94	
AIRFRAME WARRANTY			59022.39	
ENGINE WARRANTY			13858.38	
AIRFRAME FEE			148736.31	
ENGINE FEE			34923.12	
ENGINE COST			325949.25	
AVIONICS COST			350000.00	
AIRFRAME COST			1388206.00	
RESEARCH AND DEVELOPMENT			561210.69	
TOTAL FLY AWAY COST				2625365.00

Figure 1.2-3. Costing Printout

has been completed. By definition the rotor and non-rotor VTOL concepts have a zero field length. Both the augmented wing and deflected slipstream STOL concepts have different field lengths for variations in wing loading and thrust-to-weight ratio. The CTOL landing field length is only a function of wing loading and does not change with thrust-to-weight ratio variation.

1.2.1.3 Cost Analysis

The entire cost analysis task encompasses the major items of Direct Operating Cost (DOC), Indirect Operating Cost (IOC), and Total System Cost. Although these are considered as separate entities they are interrelated in context of total system cost. Total system cost is a combination of DOC and IOC. The costs are combined for total system cost to determine fare, and indicate the total economic impact. The IOC and Total System Cost models are discussed in paragraph 1.3.1.2. Only the DOC model will be discussed here. The DOC model is an adaptation of the direct expense items as outlined in reference 1.3-3 of the reference list included in this report. The formulas as given in reference 1.3-3 are derived from data on 707/DC-8 series airplanes. The maintenance formulas were derived from 707-DC-8 data as reported in the ATA Spec - 100 Groups. This data was consolidated to the following maintenance elements.

Equipment and Furnishing

Landing Gear

Other Systems

Structures

Other Power Plant

Propellers

Engines

The above items are not sufficient to cover the maintenance of the types of aircraft under consideration for the intraurban transportation system, and an additional element was added. The addition was a relationship for determining the maintenance cost for labor and material for gearboxes, clutches and shafting for V/STOL type aircraft. Further adaptation was required to modify the 707/DC-8 series maintenance formulas to the intraurban concept. Initial results show that the intraurban aircraft makes from 4800 to 10,000 flights per year with the number of flights depending upon the size of the aircraft. This is considerably more flights than the current

domestic airplane of the 707/DC-8 type fly and therefore the flight cycle influence on the maintenance cost was modified. The maintenance equations were changed to reflect a realistic cost per flight hour for an airplane flying this large number of flight cycles. The maintenance formulas are noted in paragraph 1.2.1.3.3.

The DOC model includes sub models for determining the development and flyaway cost of the airplane. The relationship between the development cost model, the flyaway cost model and the DOC is shown in the DOC flow diagram (Figure 1.2-4). The cost estimating relationships for the various DOC items are included in the following paragraphs.

The cost ground rules which form a portion of the inputs to the overall cost calculations are listed below:

- All costs are in 1970 dollars
- The production cost of aircraft is based on a production quantity of 300 airplanes. The R & D is amortized over 300 airplanes.
- Production cost for avionics is constant for all concepts at $350,000 per aircraft.
- Complete development is required for all engines.
- All flight test aircraft are eventually sold to customers and do not remain in development status.
- No major development required for avionics.
- The flight crew consists of a pilot and co-pilot. There is no cabin crew.

The parametric data inputs for the fixed wing aircraft are obtained from within the aircraft sizing model (ASSET), and are fed directly into the DOC model. The compound helicopter and autogyro are not sized in the ASSET program and the DOC for these vehicles is determined by calculations outside of the model. A sample input listing for determining the DOC/IOC and total system cost for the compound helicopter, autogyro and fixed wing aircraft are shown in paragraph 1.3.1.2. The method for determining the costs is the same for both CTOL and V/STOL except the CTOL costs are entirely calculated

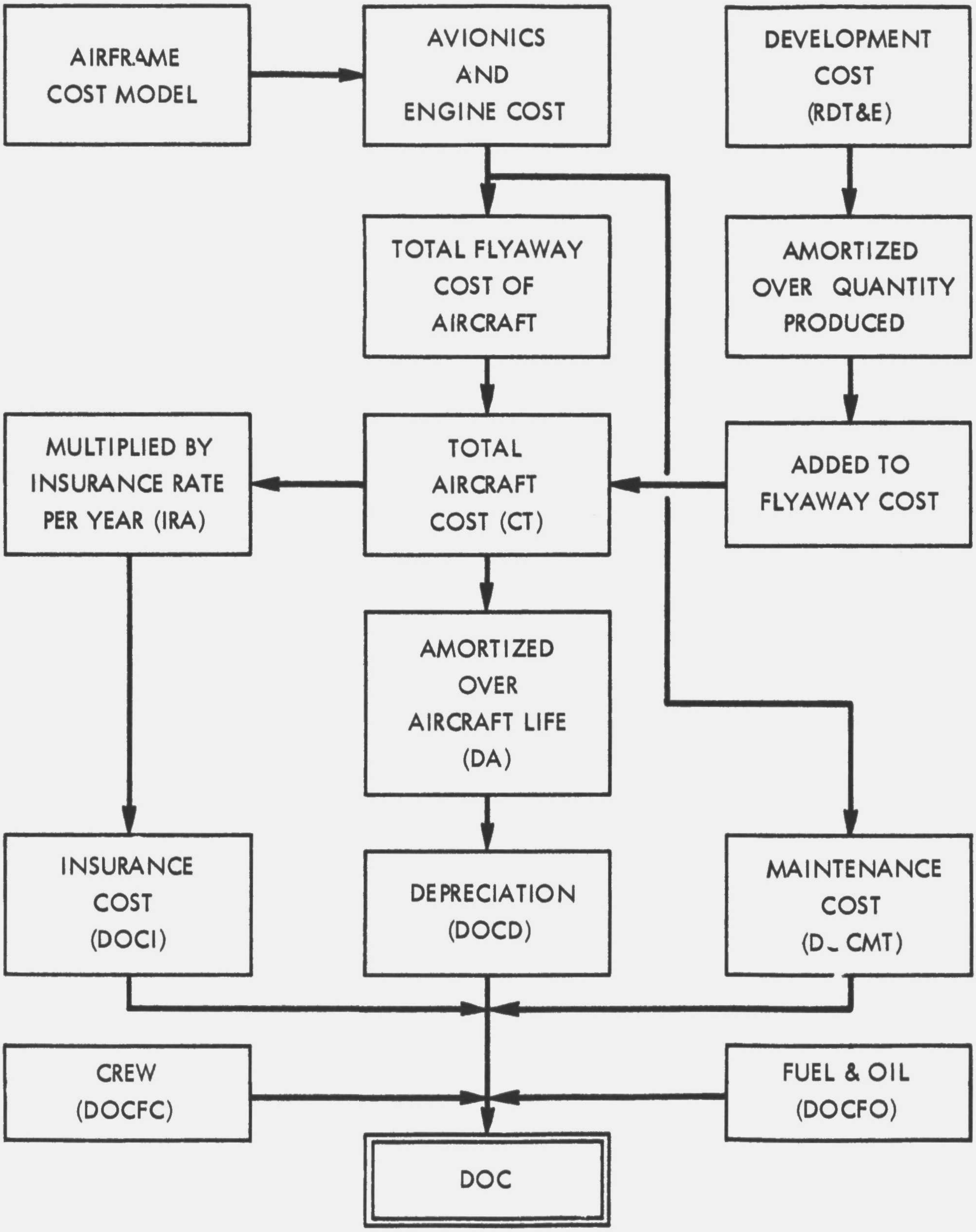

Figure 1.2-4 DOC Flow Diagram

within the model, and certain costs for the V/STOL helicopter and autogyro are calculated outside of the model and input to the program.

1.2.1.3.1 Development

The development cost includes the cost for the development of the airframe and engine. The avionics components are considered available and only technical integration is required.

The total development cost as calculated by the model is prorated over the total production quantity and added to the flyaway cost of the airplane.

The definition of the symbols for the equations and the fixed cost input factors are given in Table 1.2-1.

Research, Development, Test and Evaluation

Design Engineering Cost (DIEC)

$$\mathrm{RFDE} = 9.6\,(\mathrm{VMAX})^{0.55}\,[(\mathrm{TTREF})(\mathrm{XNENG})]^{0.88}$$

$$\mathrm{DIH} = \mathrm{RFDE}\,(\mathrm{XK1})\,(\mathrm{TAF1})$$

$$\mathrm{DIEC} = \mathrm{DIH}\,(\mathrm{DER} + \mathrm{\emptyset ER})\,(1 + \mathrm{PROFR})$$

Development Tooling Cost (DTC)

$$\mathrm{DTHB} = 0.1836\,(\mathrm{TOGW})^{0.84}\,(\mathrm{VAMX})^{1.07}\,(\mathrm{XK2})\,(\mathrm{TAF2})$$

$$\mathrm{DTH} = \mathrm{DTHB}\,(\mathrm{DR})^{0.4}$$

$$\mathrm{DTC} = \mathrm{DTH}\,(\mathrm{DTR} + \mathrm{\emptyset TR})\,(1 + \mathrm{PR\emptyset FR})$$

Development Test Article Cost (Ground test hardware) (DART)

$$\mathrm{DSTA} = (\mathrm{TAFCO})\,\mathrm{XNSTA}$$

$$\mathrm{DFTA} = (\mathrm{TAFCO})\,\mathrm{XNFTA}$$

$$\mathrm{DMTS} = (\mathrm{TADCO})\,\mathrm{XMTSF}$$

$$\mathrm{DART} = \mathrm{DSTA} + \mathrm{DFTA} + \mathrm{DMTS}$$

TABLE 1.2-1 DEFINITION OF RDT&E SYMBOLS

SYMBOL DEFINITION	SYMBOL	VALUE
Design engineering hours	RFDE	Calculated
Design engineering hours (including advanced technology)	DIH	Calculated
Design engineering cost	DIEC	Calculated
Maximum design speed - in MPH	VMAX	345
Total maximum thrust of aircraft	TTREF	Calculated
Number of engines per aircraft	XNENG	4
Design engineering complexity factor	XK1	input
Technology advance factor	TAF1	input
Design engineering labor rate	DER	input
Engineering overhead rate	ØER	input
Profit rate - in decimal form (0.10)	PROFR	input
Cost for static test articles	DSTA	Calculated
Cost for fatigue test articles	DFTA	Calculated
Cost for miscellaneous test support articles	DMTS	Calculated
Production cost for airframe for flight test vehicles	TAFCO	Calculated
Cumulative number of flight test vehicles	CXNYO	6
Number of static test articles	XNSTA	input
Number of fatigue test articles	XNFTA	input
Number of miscellaneous test articles	XMTSF	input
Production rate for flight test vehicles - number per month	DR	2
Tool design labor rate	DTR	input
Tool design overhead rate	ØTR	input
Flight test technology advancement factor	TAF3	input

TABLE 1.2-1 DEFINITION OF RDT&E SYMBOLS (Continued)

SYMBOL DEFINITION	SYMBOL	VALUE
Development cost for turbojet engine	DCENG1	Calculated
Numerical constant for turbojet engine development	CEDCF1	100,000
Exponent for turbojet engine development	CEDCE	.722
Technology advancement for turbojet engine development	TAF4A	input
Number of turbojet engines produced to certification	DQ1	100
Development cost for turboprop engine	DCENG2	Calculated
Numerical constant for turboprop engine development	CEDCF2	4.9×10^6
Total shaft horsepower per engine	ESHP	Calculated
Avionics spares factor	AVDSF	.25
Total cost of avionics for flight test vehicles	RAVC	2.4×10^6
Design cost for special support equipment	DSSE	Calculated
Special support equipment cost factor	DSSEF	.05
Development - Operator trainer	DØT	input
Development - Maintenance trainer	DMT	input
Development - Technical data	DDATA	Calculated
Technical data cost factor	DTDF	.02
Flight test cost without profit	RFFT	Calculated
Complexity factor for Flight Test	XK3	input
Flight test cost including profit	DFT	Calculated
Take-off gross weight	TØGW	Calculated
Development tooling complexity factor	XK2	input
Technology advancement factor	TAF2	input
Design tooling hours - for rate for prototypes	DTH	Calculated

TABLE 1.2-1 DEFINITION OF RDT&E SYMBOLS (Continued)

SYMBOL DEFINITION	SYMBOL	VALUE
Design tooling hours - basic tooling	DTHB	Calculated
Exponent for turboprop engine development	CEDTP	.35
Complexity factor for turbojet engine development	XK4	input
Technology advancement factor for turboprop	TAF4B	input
Complexity factor for turboprop engine development	XK5	input
Number of turboprop engines produced to certification	DQ2	100
Avionics development cost	DAV	Calculated
Avionics cost per pound for development - $/lb	DPAVD	2630
Weight of avionics	WAV	Calculated
Avionics fixed cost - $	FAVDC	100,000
Avionics technology advancement factor*	TAF5	input
Development spares cost	DSPAR	Calculated
Airframe spares factor	ADSF	.18
Engine spares factor	EDSF	.33
Total cost for engines for flight test vehicles	RTENGC	Calculated

* See Tables 1.2-2, 1.2-3 and 1.2-4

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Flight Test Cost (DFT)

$$RFFT = 0.66\,(CXNY\emptyset)^{1.1}\,(T\emptyset GW)^{0.8}\,(VMAX)^{0.9}$$

$$DFT = RFFT\,(1 + PR\emptyset FR)\,(TAF3)\,(XK3)$$

Engine Development Cost (DCENG1; DCENG2)

$$DCENG1 = CEDCF1\,(TTREF)^{CEDCE}\,CEDCM1\,(TAF4A)$$

$$CEDCM1 = (DQ1)^{0.082}\,(XK4)$$

$$DCENG2 = CEDF2\,(ESHP)^{CEDTP}\,(CEDCM2)\,(TAF4B)$$

$$CEDCM2 = (DQ2)^{0.09}\,(XK5)$$

Avionics Development Cost (DAV)

$$DAV = [DPAVD\,(WAV) + FAVDC]\,(TAF5)$$

Development Spares Cost (DSPAR)

$$DSPAR = [ADSF\,(TAFCO) + EDSF\,(RTENGC)] * CXNY\emptyset + AVDSF\,(RAVC)$$

$$RTENGC = (RCPE1 + RCPE2) * XNENG$$

Special Support Equipment (DSSE)

$$DSSE = DSSEF\,(DIEC)$$

Development Operator Trainer (Simulator) (DØT)

DØT (input)

Development Maintenance Trainer (DMT)

DMT (input)

Development Technical Data (DDATA)

$$DDATA = DTDF\,(DIEC)$$

Total RDT&E

$$RDT\&E = [\ DIEC + DTC + DART + DFT + DCENG + DAV + DSPAR + DSSE + DOT + DMT + DDATA\ ]\ /\ XNV$$

Many of the inputs to the development cost relationships are obtained directly from within the ASSET program for the fixed wing aircraft, others are analyzed outside the program and input. A portion of those that are input are the XK factors which reflect differences in complexity due to configuration and the TAF factors which reflect differences in technology. The XK factors are estimated by comparison of the complexity of the configuration to the CTOL configuration which is the baseline (1.0). For instance, the added complexity of the tilt wing is due to the requirement of the gearing and shafting, controls, etc., which influences the design, engineering, test article cost, flight test and ground test. The same philosophy is applied to engines. The cost due to technology advancement is derived through a statistical analysis of engine data. A multiple correlation was performed which resulted in cost estimating relationships based on parameters such as engine inlet temperature, thrust-to-weight ratio, pressure ratio, thrust or ESHP, and the physical characteristics of dry weight, length and diameter. This analysis provided the sensitivity of the engine production cost to the thrust-to-weight ratio, and the method for estimating the cost impact resulting from the higher thrust-to-weight ratios provided by advanced technology. These complexity factors for the various aircraft types are shown in Tables 1.2-2, 1.2-3 and 1.2-4. These factors are applied to the cost estimating relationships as indicated.

1.2.1.3.2 Production

The production cost for each concept, including rotary wing, is determined by applying labor hours and material dollars to the weight of each component of the aircraft. The labor hours are then converted to dollars by the application of the 1970 production labor rate. The labor rate includes the cost for the direct labor and the overhead charges.

The complexity factor for production is applied to the labor hours and material dollars assigned to each element. The factors for

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TABLE 1.2-2 COMPLEXITY AND ADVANCED TECHNOLOGY FACTORS FOR DEVELOPMENT

		1975			1985			
	Symbol	CTOL	Deflected Slipstream STOL	Tilt Wing V/STOL	CTOL	Deflected Slipstream STOL	Tilt Wing V/STOL	Augmented Wing
Complexity Factors								
Design Engineering	XK1	1.0	1.1	1.3	1.0	1.1	1.3	1.2
Development Tooling	XK2	1.0	1.0	1.2	1.0	1.0	1.2	1.1
Flight Test	XK3	1.0	1.2	1.5	1.0	1.2	1.5	1.2
Engine Development								
Turbojet	XK4	1.0		-	1.0	-	-	1.3
Turboprop	XK5	1.0	1.0	1.0	1.0	1.0	1.0	-
Technology Advancement								
Design Engineering	TAF1	1.0	1.0	1.0	1.0	1.1	1.3	1.3
Development Tooling	TAF2	1.0	1.0	1.0	1.0	1.1	1.2	1.2
Flight Test	TAF3	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Engine Development								
Turbojet	TAF4A	1.0	-	-	1.315	-	-	1.315
Turboprop	TAF4B	-	1.0	1.0	-	1.245	1.245	-
Avionics	TAF5	1.0	1.0	1.0	1.0	1.0	1.0	1.0

TABLE 1.2-3 COMPLEXITY AND ADVANCED TECHNOLOGY FACTORS FOR PRODUCTION

	Symbol	1975			1985			
		CTOL	Deflected Slipstream STOL	Tilt Wing V/STOL	CTOL	Deflected Slipstream STOL	Tilt Wing V/STOL	Augmented Wing
Complexity Factors								
Turbojet Engine	XK6	-	-	-	1.0	-	-	1.20
Turboprop Engine	XK7	1.0	1.0	1.1	-	1.0	1.1	-
Technology Advancement								
Turbojet Engine	TAF6	-	-	-	1.315	-	-	1.315
Turboprop Engine	TAF7	1.0	1.0	1.0	-	1.245	1.245	-

TABLE 1.2-4 COMPLEXITY AND ADVANCED TECHNOLOGY FACTORS FOR DEVELOPMENT AND PRODUCTION

		1975	1985	
	Symbol	Compound Helicopter	Compound Helicopter	Autogyro
Development				
Complexity Factors				
Design (Airframe)	XK1	1.2	1.2	1.2
Tooling	XK2	1.2	1.2	1.2
Flight Test	XK3	1.5	1.5	1.5
Engine Dev.				
Turbojet	XK4	1.4	1.2	1.2
Turboprop	XK5	1.1	1.1	1.1
Tech. Advancement				
Design (Airframe)	TAF1	1.0	1.3	1.3
Tooling	TAF2	1.0	1.2	1.2
Flight Test	TAF3	1.0	1.0	1.0
Engine Dev.				
Turbojet	TAF4A	1.1	1.1	1.1
Turboprop	TAF4B	1.0	1.1	1.1
Avionics	TAF5	1.0	1.0	1.0
Production				
Complexity Factor				
Turbojet Eng.	XK6	1.1	1.1	1.1
Turboprop Eng.	XK7	1.0	1.0	1.0
Tech. Advancement				
Turbojet Eng.	TAF6	1.0	1.0	1.0
Turboprop Eng.	TAF7	1.0	1.0	1.0

advanced technology are assigned to each element with consideration given to the amount of advanced material used and its cost in relation to aluminum. The labor hours and material dollar factors have been placed in the following format.

- Wing
- Tail
- Body
- Landing Gear
- Flight Controls
- Nacelles
- Propulsion System
  - Engine Installation
  - Propellers
  - Fuel System
  - Start System
  - Exhaust
  - Engine Controls
  - Water Injection
  - Fire Extinguisher
  - Cooling
  - Thrust Reverse
  - Lube Systems
- Instruments
- Hydraulic
- Electrical
- Avionics Installation

Furnishings and Equipment

Air Conditioning

Anti-Icing

Technical Integration

APU

Gearbox and Shafting

Tail Rotor

In addition to the costs associated with the above mentioned aircraft components there are costs which are related to functions and others that are simply additive. These are listed below:

Sustaining Engineering

Technical Data

Tool Maintenance - Production

Engineering Change Orders

Quality Assurance

Miscellaneous

Airframe Warranty

Airframe Fee

Engine Fee

The remainder of the flyaway cost elements includes the engine and the avionics production cost. The avionics cost is constant for all configurations and is estimated at $350,000 per aircraft. The avionics equipment list is presented in paragraph 1.1.2.6. The engine production costs are estimated by the following estimating relationships:

Turbojet Engine Production Cost (CPE1)

$$\text{CPE1} = 165\ (\text{TTREF})^{0.856}\ (\text{PPQ})^{-0.120}\ (\text{TAF6})\ (\text{XK6})$$

Turboprop Engine Production Cost (CPE2)

$$CPE2 = 5150\,(ESHP)^{0.459}\,(PPQ)^{-0.109}\,(TAF7)\,(XK7)$$

where:

TTREF = maximum thrust per engine

PPQ = number of production engines

$\left.\begin{matrix}TAF6\\TAF7\end{matrix}\right\}$ = technology advancement factor (see Table 1.2-3)

$\left.\begin{matrix}XK6\\XK7\end{matrix}\right\}$ = complexity of engine compared to standard engine

ESHP = equivalent shaft horsepower

1.2.1.3.3 Operations

The direct operating cost model is consistent in format with the ATA method of determining DOC, and in some instances use the same cost factors.

The crew cost equation is based on the recent agreement between the pilot's association and L.A. Airways (Reference 1.2-1). The recent agreement sets forth criteria for pay in terms of vehicle size, speed and pilot seniority. These factors were used to establish the cost estimating relationship for both the conventional and V/STOL aircraft. The fuel and oil cost is based on the fuel and oil consumption rates per hour and their respective cost per pound. The costs that were used are noted on the input sheets. The insurance is simply the insurance rate multiplied by the fly-away cost of the aircraft. The insurance rate is the same as used by the ATA method. The depreciation of the aircraft and spares follow the same method as used by the ATA. The spares percentages and depreciation period are noted in the input listing. The DOC model was used in the Parametric Data Development (Section 1.2) and in the Synthesis and Optimization (Section 1.3) and the results are exhibited in these sections. A more detailed sample of the total cost (DOC/IOC/TSC) is shown in Paragraph 1.3.1.2.10.

DOC Estimating Relationships in Dollars per Year
(See Note 1)

- Crew Cost - DOCFC

$$DOCFC = [7500 + 28.5\ VCRUZ + 0.045\ (T\emptyset GW) + 3.0\ (U)]\ NC\ \frac{U}{960}\ (CTOL)$$

$$DOCFC = [10,000 + 32.5\ VCRUZ + 0.05\ (T\emptyset GW) + 6.0\ (U)]\ NC\ \frac{U}{960}\ (V/STOL)$$

- Fuel and Oil - DOCFO

$$DOCFO = 1.02\ [FB/TB(CFT) + XNENG(COT)\ 0.135]\ U$$

- Insurance - DOCI

$$DOCI = IRA\ (CT)$$

- Depreciation - DOCD

$$DOCD = [CT + KSPA\ (CT - TENGC - AVC) + KSPE\ (TENGC) + KSPAV\ (AVC)]\ /DA$$

- Maintenance - DOCMT

  Maintenance Cost (\$ - per year)

- Equipment and Furnishings - labor - (CLEF)

$$CLEF = \left[\left(0.3 + 2.0 * \frac{AFWT}{10^6}\right) TF + 0.1 + 9\ \frac{(AFWT)}{10^6}\right] \frac{RL(U)}{TB}$$

- Equipment and Furnishings - Material - (CMEF)

$$CMEF = \left[\left(0.2 + 7 * \frac{AFWT}{10^6}\right) TF + 1.0 + 21\ \frac{(AFWT)}{10^6}\right] \frac{U}{TB}$$

- Landing Gear - labor - (CLLG)

$$CLLG = \left[0.3 + 3\ \frac{(AFWT)}{10^6}\right] \frac{RL(U)}{TB}$$

- Landing Gear - Material - (CMLG)

$$CMLG = \left[1.5 + 0.7 \frac{(TAPC)}{10^6}\right] \frac{U}{TB}$$

- Tires and Brakes - Material - CMTB

$$CMTB = \left[1.2 + 100 \frac{(AFWT)}{10^6}\right] \frac{U}{TB}$$

- Other Systems - Labor - CLQS

$$CLOS = \left[0.006 \; (AFWT)^{0.5} \; TF + 0.0016 \; (AFWT)^{0.5}\right] \frac{RL(U)}{TB}$$

- Other Systems - Material - CMOS

$$CMOS = \left[1.4 + 2.0 \frac{TAPC}{10^6} \; TF + 0.8 + 0.6 \frac{(TAPC)}{10^6}\right] \frac{U}{TB}$$

- Structures - Labor - CLSTR

$$CLSTR = \left[0.1 + 20 \frac{(AFWT)}{10^6}\right] \frac{RL}{TB} (U)$$

- Structures - Material - CMSTRA

$$CMSTR = \left[0.6 + 0.8 \frac{(TAPC)}{10^6}\right] \frac{U}{TB}$$

- Other Power Plant - Labor - CLOPP

$$CLOPP = \left[0.0009 \; (AFWT)^{0.5} \; TF + 0.0003 \; (AFWT)^{0.5}\right] \frac{RL \; (XNENG)(U)}{TB}$$

- Other Power Plant - Material - CMOPP

$$CMOPP = \left[\left(0.3 + 0.8\,\frac{(TAPC)}{10^6}\right) TF + 0.2 + 0.05\,\frac{(TAPC)}{10^6}\right] \frac{XNENG}{TB}\,(U)$$

- Propeller - Labor - CLP

$$CLP = \left[0.01\,(TF) + 0.005\right] WPROP^{0.5}\,(RL)\,\frac{NP}{TB}\,(U)$$

- Propeller - Material - CMP

$$CMP = \left[(3TF + 2)\,CP\,(NP)\right] \frac{U}{TB * 10^5}$$

- Gear and Shafting - Labor - CLG

$$CLG = [0.057 + 0.00018\,(WG)]\,RL\,(U)$$

- Gear and Shafting - Material - CMG

$$CMG = \left[0.21 + 14\,\frac{(WG)}{10^6} + 3.1\,\frac{CG}{10^6}\right] \frac{TF}{TB}\,(U) + \left[0.6 + \frac{112WG}{10^6} + \frac{3.1CG}{10^6}\right] \frac{U}{TB}$$

- Engine - Labor - Turbojet - CLEJ

$$CLEJ = \left[\left(0.4 + 0.018 * \frac{TTREP}{1000}\right) TF + 0.2 + 0.012\,\frac{TTREP}{1000}\right] \frac{XNENG(RL)U}{TB}\,(TJMF)$$

- Engine Labor - Turboprop - CLEP

$$CLEP = \left[\left(0.6 + 0.027 * \frac{ESHP}{1000}\right) TF + 0.2 + 0.012 * \frac{ESHP}{1000}\right] \frac{XNENG(RL)U}{TB}\,(TPMF)$$

- Engine - Material - Turbojet - CME

$$CME = \left[3.8\ (TF) + 2.4\right] \frac{CPE1\ (XNENG)\ U}{TB * 10^5} * (TJMF)$$

- Engine - Material - Turboprop - CMTP

$$CMTP = \left[5.7\ (TF) + 2.4\right] \frac{CPE2\ (XNENG)\ U}{TB * 10^5} * (TPMF)$$

Total Labor Cost per year - TLAB

$$TLAB = CLEF + CLLG + CLOS + CLSTR + CLOPP + CLP + CLG + CLEJ + CLEP$$

Total Material Cost per year - TMAT

$$TMAT = CMEF + CMLG + CMTB + CMOS + CMSTR + CMOPP + CMP + CMG + CME + CMTP$$

Total Maintenance - DOCMT

$$DOCMT = TLAB + TMAT$$

$$\text{Maintenance Burden} = MABURD = 1.30 * TLAB$$

Total DOC ($ per year)

$$DOC = DOCFC + DOCFO + DOCI + DOCD + DOCMT + MABURD$$

$$\text{DOC per flight hour } DOCFH = \frac{DOC}{U}$$

$$\text{DOC per statute mile} = DOCST = \frac{DOCFH}{VB}$$

$$\text{DOC per seat mile} = DOCSM = \frac{DOCST}{XNPASS}$$

$$\text{DOC per passenger mile} = \frac{DOCSM}{XLF}$$

(Note 1 - See Table 1.2-5 for symbol definitions.)

TABLE 1.2-5 DEFINITION OF DOC SYMBOLS

SYMBOL DEFINITION	SYMBOL	VALUE
Cruise speed	VCRUZ	Calculated
Takeoff gross weight	TOGW	Calculated
Utilization per year	U	2000
Block fuel - pounds	FB	Calculated
Block time - hours	TB	Calculated
Fuel cost - $/lb	CFT	.015
Number of engines	XNENG	4
Oil cost - $/lb	COT	.926
Insurance cost rate per year	IRA	3%
Flyaway cost - including development	CT	Calculated
Spares factor for airframe	KSPA	.15
Production cost for engines - per aircraft	TENGC	Calculated
Production cost for avionics - per aircraft	AVC	$350,000
Spares factor for engines	KSPE	.50
Spares factor for avionics	KSPAV	.50
Depreciation period - years	DA	12
Airframe Weight (weight empty minus weight of engines and props)	AFWT	Calculated
Maintenance labor rate	RL	5.00
Airframe production cost	TAPC	Calculated
Weight of propeller - per prop	WPROP	Calculated
Number of props	NP	4
Total Flight time per flight	TF	Calculated
Production cost - per prop	CP	Calculated

TABLE 1.2-5 DEFINITION OF DOC SYMBOLS (Continued)

SYMBOL DEFINITION	SYMBOL	VALUE
Weight of shafting and clutch	WG	Calculated
Production cost of shafting, gearing and clutch	CG	Calculated
Maximum thrust per engine	TTREP	Calculated
Turbojet maintenance factor	TJMF	1.0 (if turbojet); 0 (if turboprop)
Equivalent shaft horsepower	ESHP	Calculated
Turboprop maintenance factor	TPMF	1.0 (if turboprop); 0 (if turbojet)
Production cost for turbojet - per engine	CPE1	Calculated
Production cost for turboprop - per engine	CPE2	Calculated
Number of seats	XNPAS	input
Load factor	XLF	input

1.2.1.4 Optimization Analysis (Fixed Wing Aircraft)

The CTOL and deflected slipstream STOL concepts are analyzed in terms of wing loading and thrust loading for the 1975 and 1985 time periods and the augmentor wing STOL is analyzed in these terms only for the 1985 time period. The 1975 and 1985 tilt wing VTOL, with their fixed thrust/weight requirements, and considered only in terms of wing loading.

The airplanes synthesized in the 1985 period make maximum utilization of all three of the technology areas (aerodynamics, structures and propulsion). The approaches analyzed in this time period are: CTOL, deflected slipstream STOL, and augmented wing STOL.

- Figure 1.2-5 - 1975 IOC CTOL
- Figure 1.2-6 - 1975 IOC Deflected Slipstream STOL
- Figure 1.2-7 - 1985 IOC CTOL
- Figure 1.2-8 - 1985 IOC Deflected Slipstream STOL
- Figure 1.2-9 - 1985 IOC Augmentor Wing STOL

All of these figures show the effect of wing loading and thrust-to-weight ratio variation for the basic 60-passenger requirement. The effect on takeoff gross weight, flyaway cost and DOC are shown with the takeoff and landing field length constraints superimposed on each of these plots. The intersection point of the takeoff and landing field length requirement is the optimum combination of wing loading and thrust-to-weight ratio to achieve the minimum takeoff gross weight for a given field length requirement.

1.2.1.5 Trade-Off Studies

In order to provide a valid relative performance ranking for the selection of the candidates, a comprehensive trade-off analysis is made to insure that the candidate system design has the best system characteristics.

The trade-off studies conducted on each of the approach concepts consists of variations in the passenger capacity and field requirements for the CTOL and STOL approaches. For the tilt wing VTOL, variations in the

PARAMETRIC AIRCRAFT SYNTHESIS - INTRAURBAN TRANSPORTATION SYSTEMS STUDY

- CONVENTIONAL TAKEOFF AND LANDING (CTOL)
- PROP POWERED - 1975 IOC
- SIXTY PASSENGERS

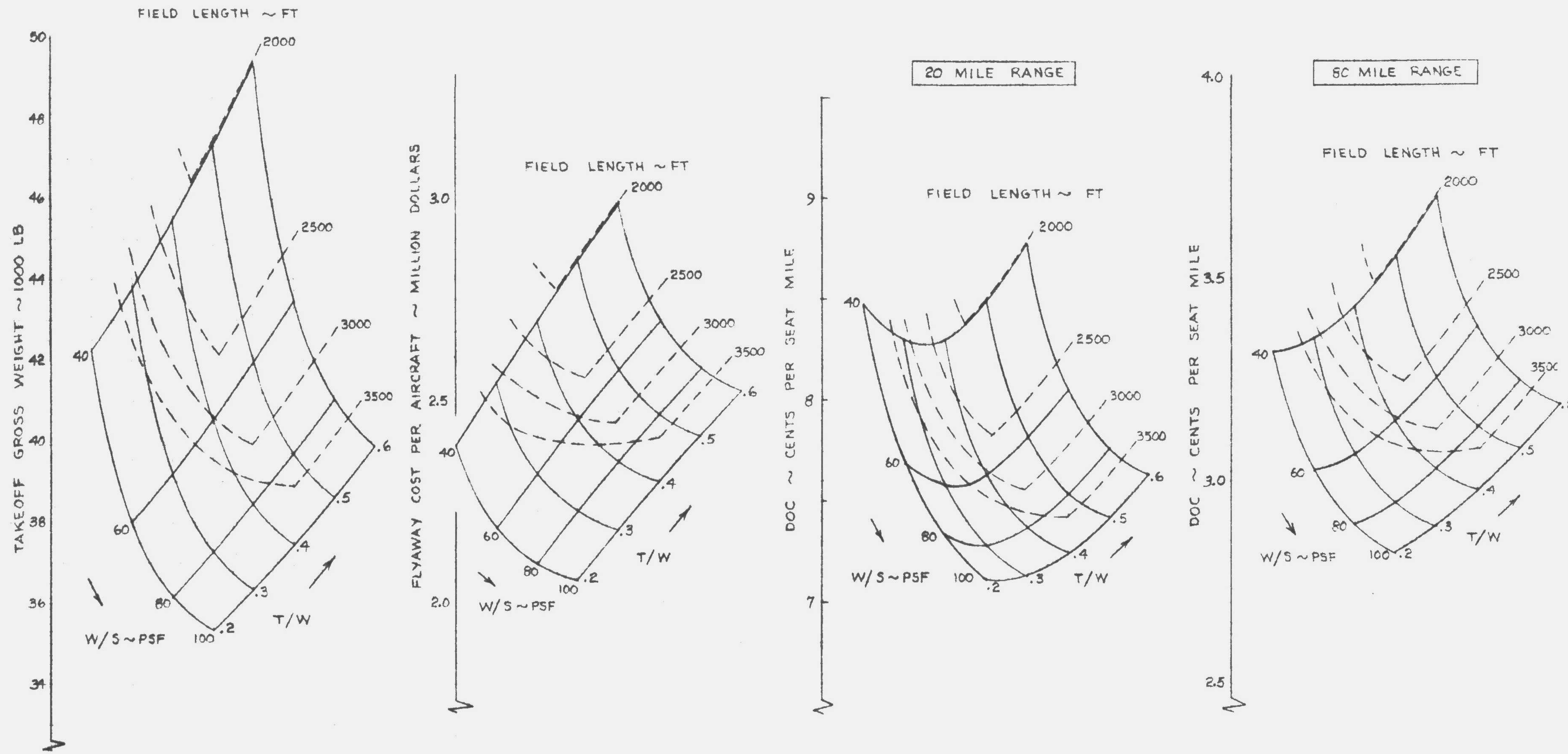

FIGURE 1.2-5. 1975 CONVENTIONAL TAKEOFF AND LANDING (CTOL) - PARAMETRIC AIRCRAFT SYNTHESIS

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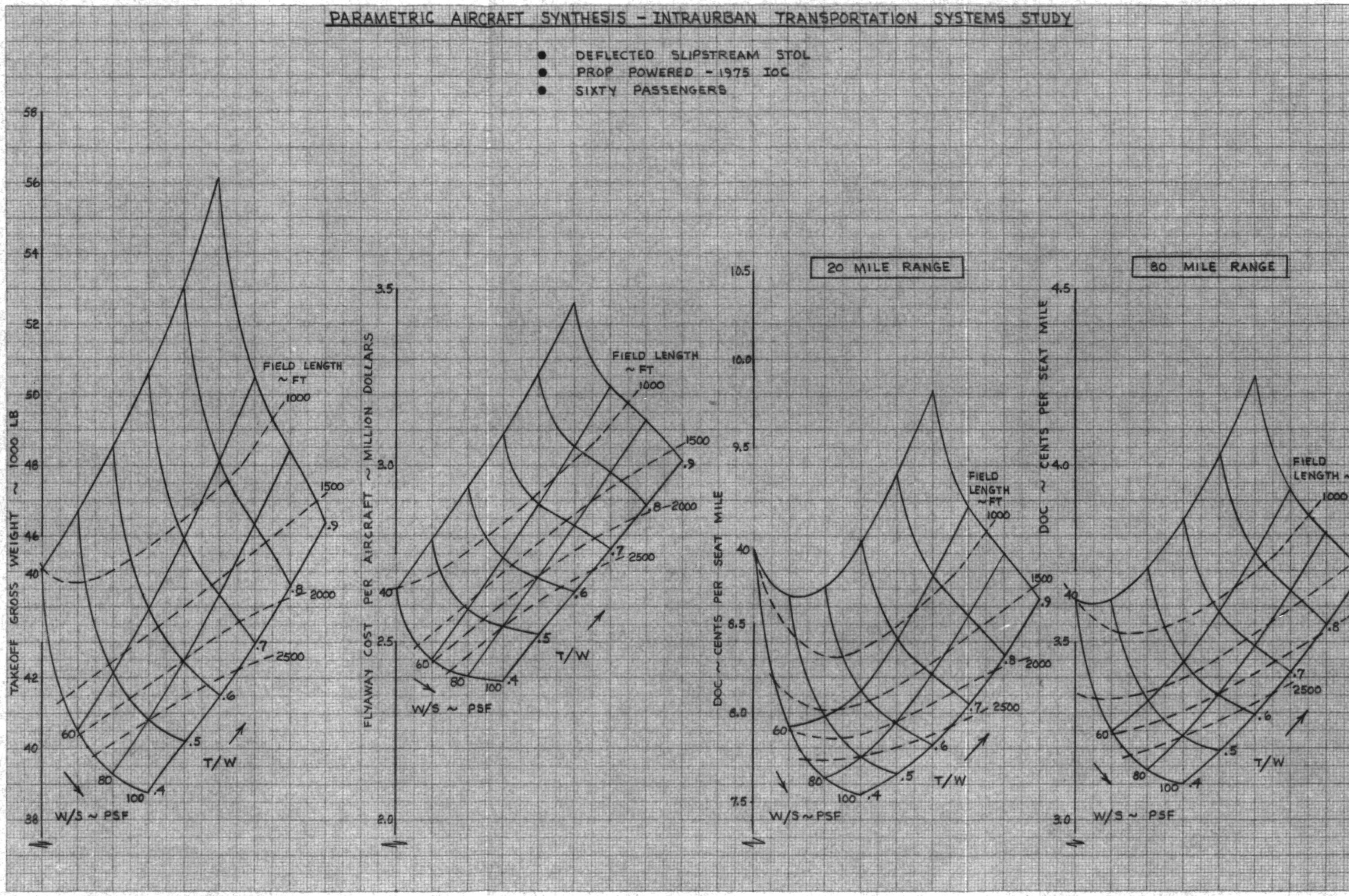

FIGURE 1.2-6. 1975 DEFLECTED SLIPSTREAM STOL - PARAMETRIC AIRCRAFT SYNTHESIS

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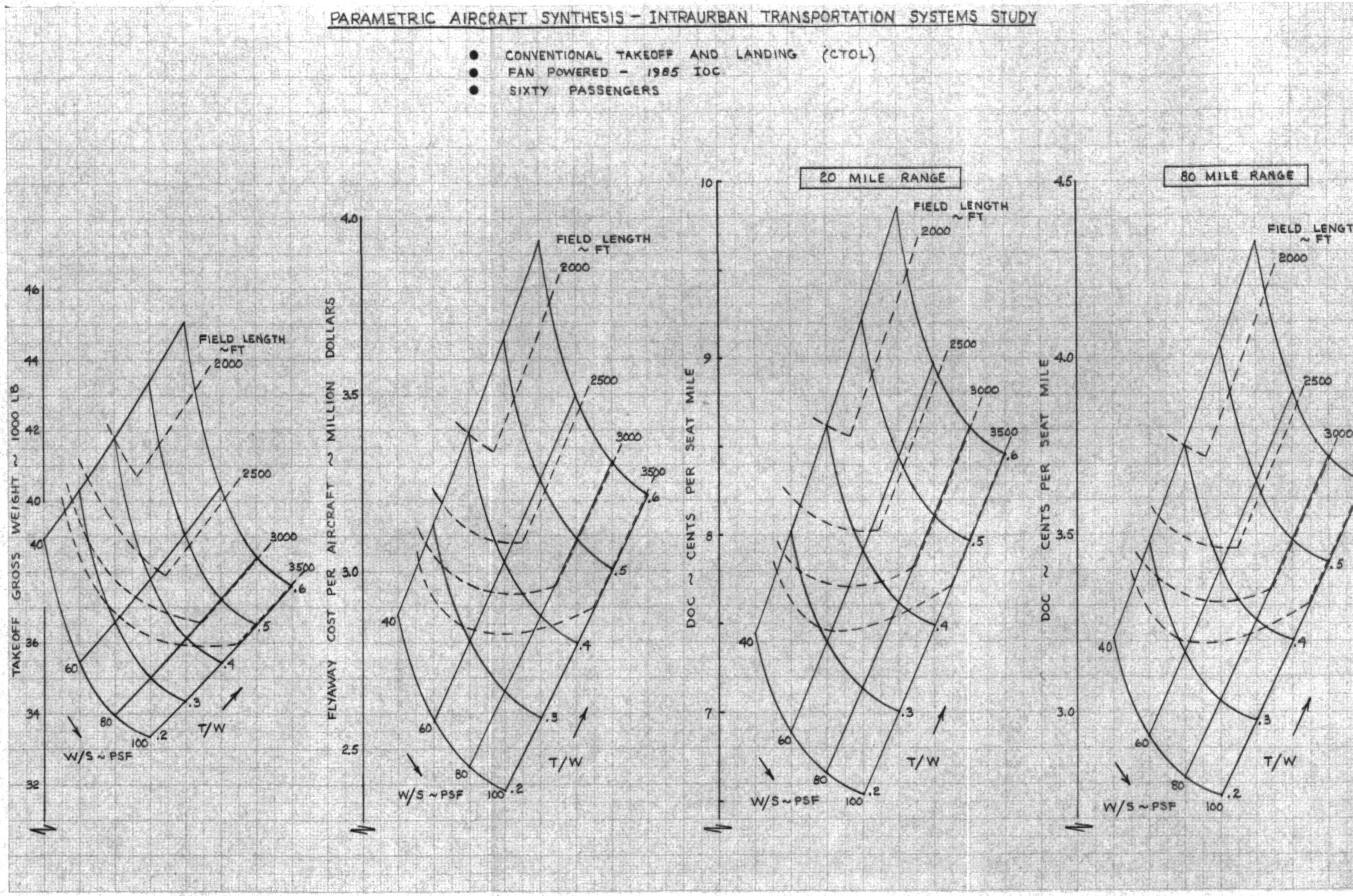

FIGURE 1.2-7. 1985 CONVENTIONAL TAKEOFF AND LANDING (CTOL) - PARAMETRIC AIRCRAFT SYNTHESIS

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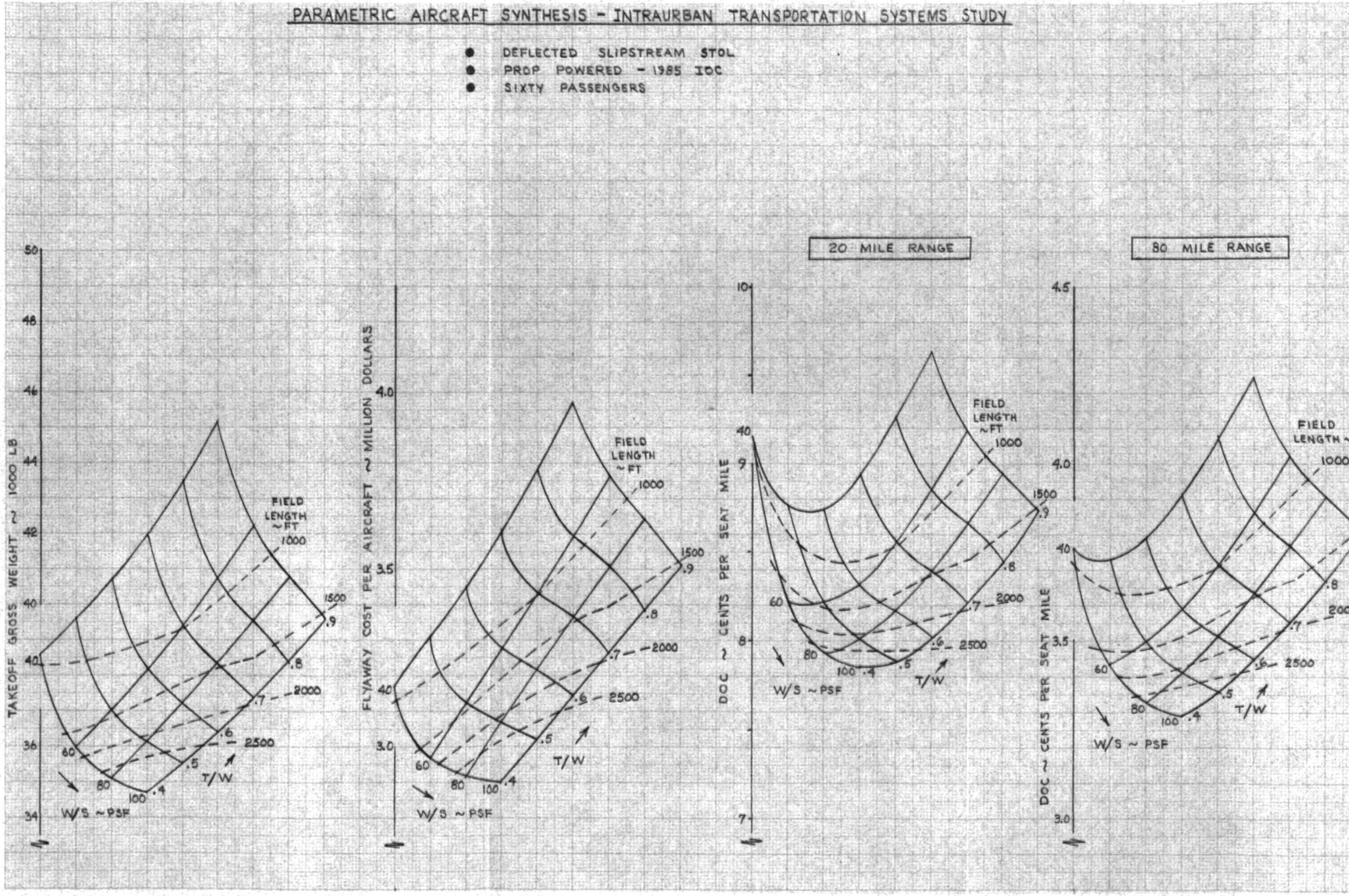

FIGURE 1.2-8. 1985 DEFLECTED SLIPSTREAM STOL - PARAMETRIC AIRCRAFT SYNTHESIS

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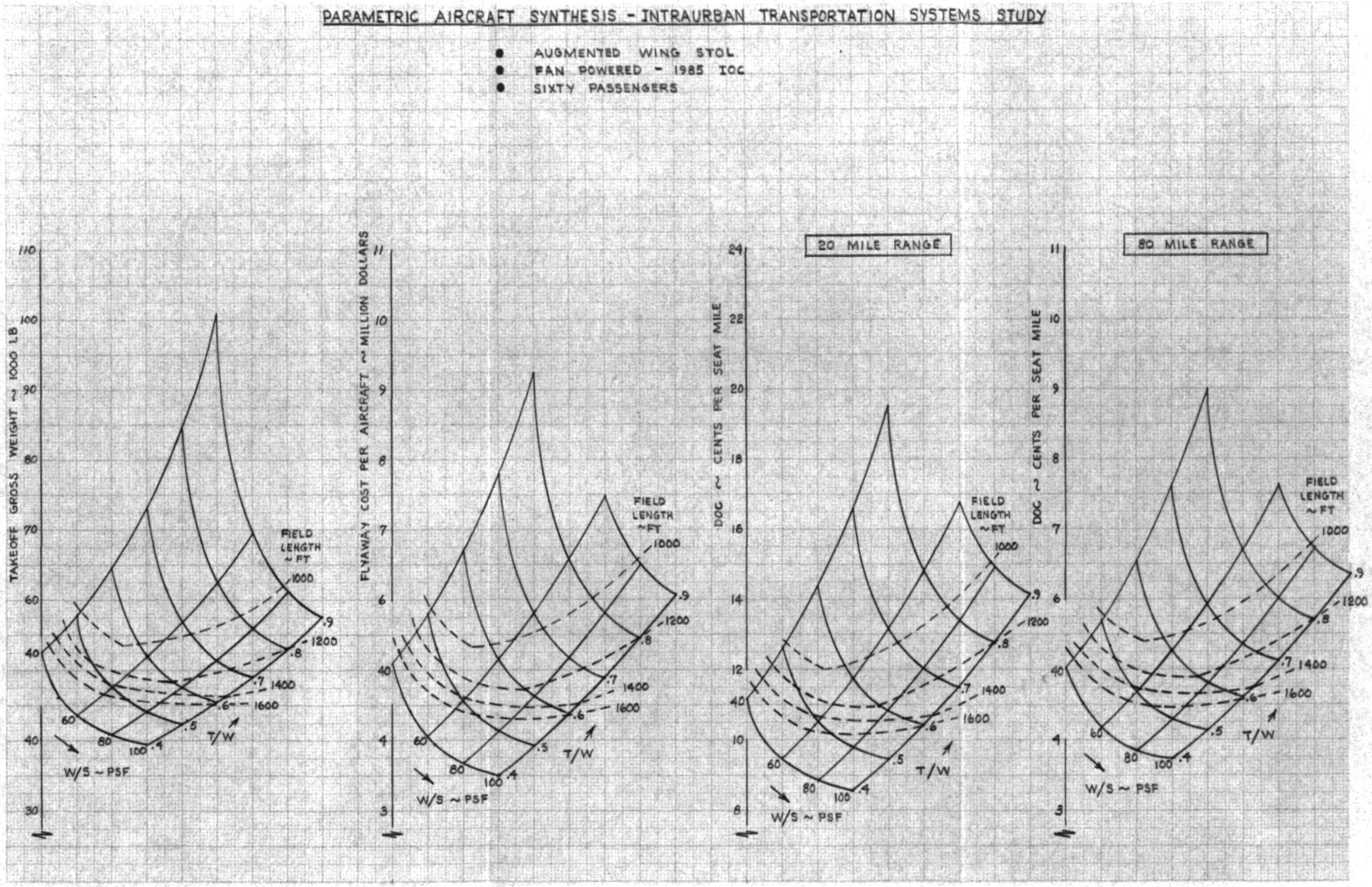

FIGURE 1.2-9. 1985 AUGMENTED WING STOL - PARAMETRIC AIRCRAFT SYNTHESIS

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passenger capacity and wing loading are made. These results are presented in Figures 1.2-10 thru 1.2-12 for the 1975 time period and in Figures 1.2-13 through 1.2-16 for the 1985 IOC time period.

1.2.1.6 Synthesis of Optimized Aircraft Characteristics

Each of the approach concepts has been exercised through a range of takeoff and landing field length requirements and passenger payload capability. The resulting synthesis aircraft characteristics are summarized on Tables 1.2-6 through 1.2-12. It is these characteristics that are matched with the operational requirements, market demand and IOC data to get the total system synthesis.

1.2.1.7 Sensitivity Analysis

Aircraft system sensitivities to major design parameters are presented in Figures 1.2-17 through 1.2-20 as a percentage variation in takeoff gross weight, flyaway cost and DOC versus the corresponding param- et variation in percentages. These design parameters include thrust-to-weight ratio, wing loading, fuel fraction, airframe structural weight fraction, and engine weight. In addition to the design parameters, the following costing parameters are investigated: number of production aircraft, research and development cost, airframe cost, block time and maintenance cost. For each of the applicable concepts, both the 1975 and 1985 technology analysis is included on the same figure.

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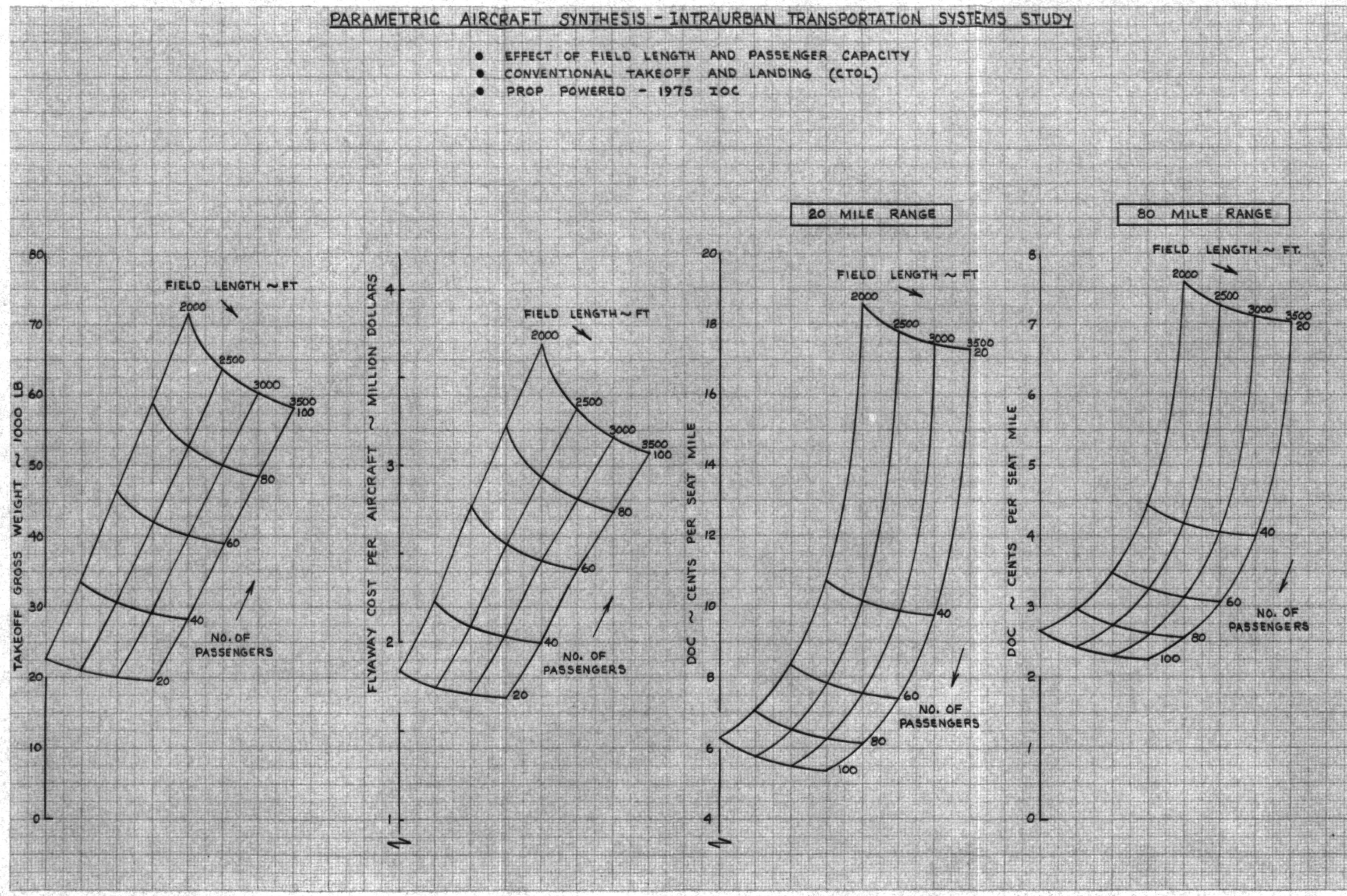

FIGURE 1.2-10. EFFECT OF FIELD LENGTH AND PASSENGER CAPACITY ON THE 1975 CTOL AIRCRAFT CONCEPT

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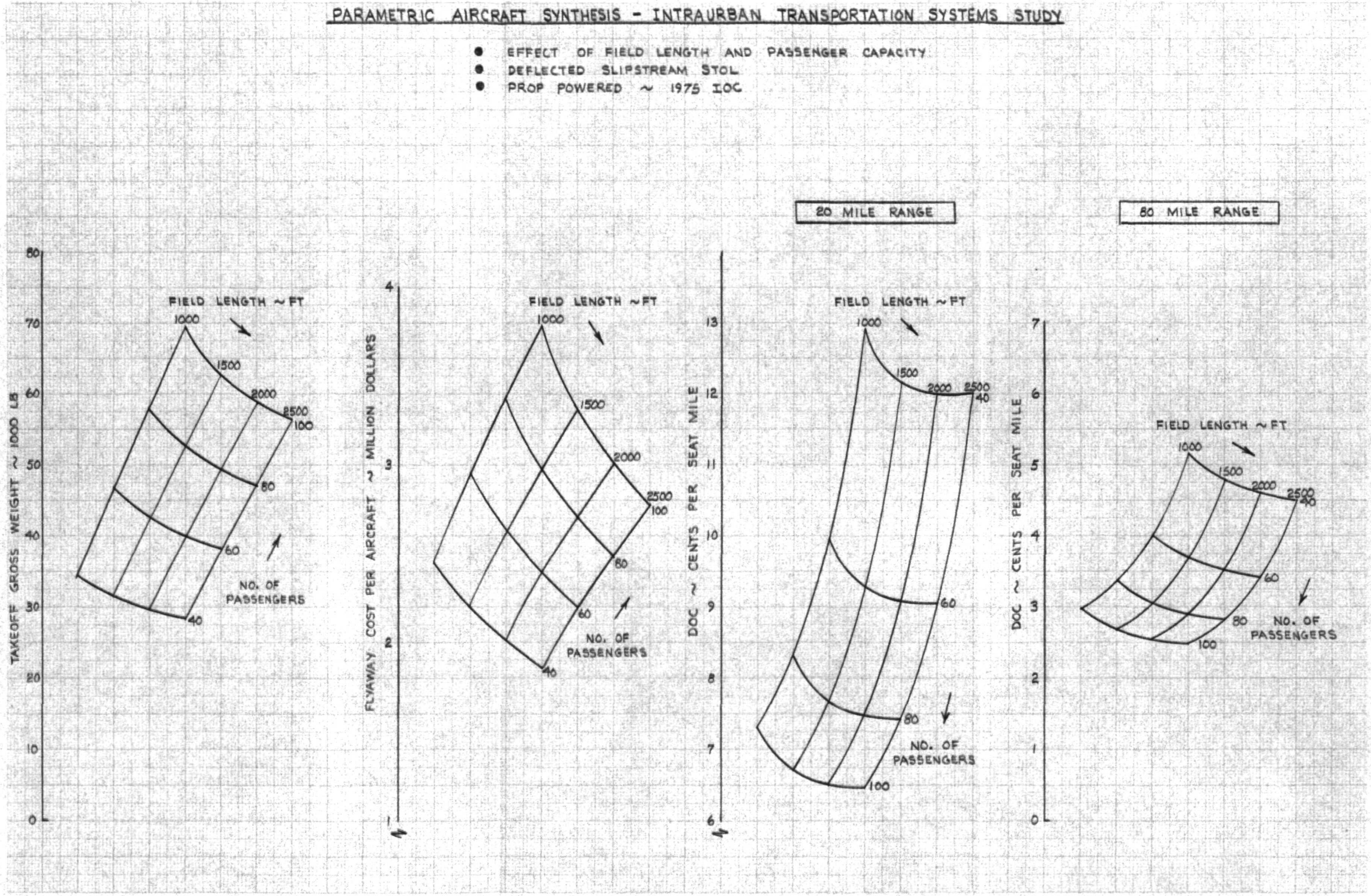

FIGURE 1.2-11. EFFECT OF FIELD LENGTH AND PASSENGER CAPACITY ON THE 1975 DEFLECTED SLIPSTREAM STOL AIRCRAFT CONCEPT

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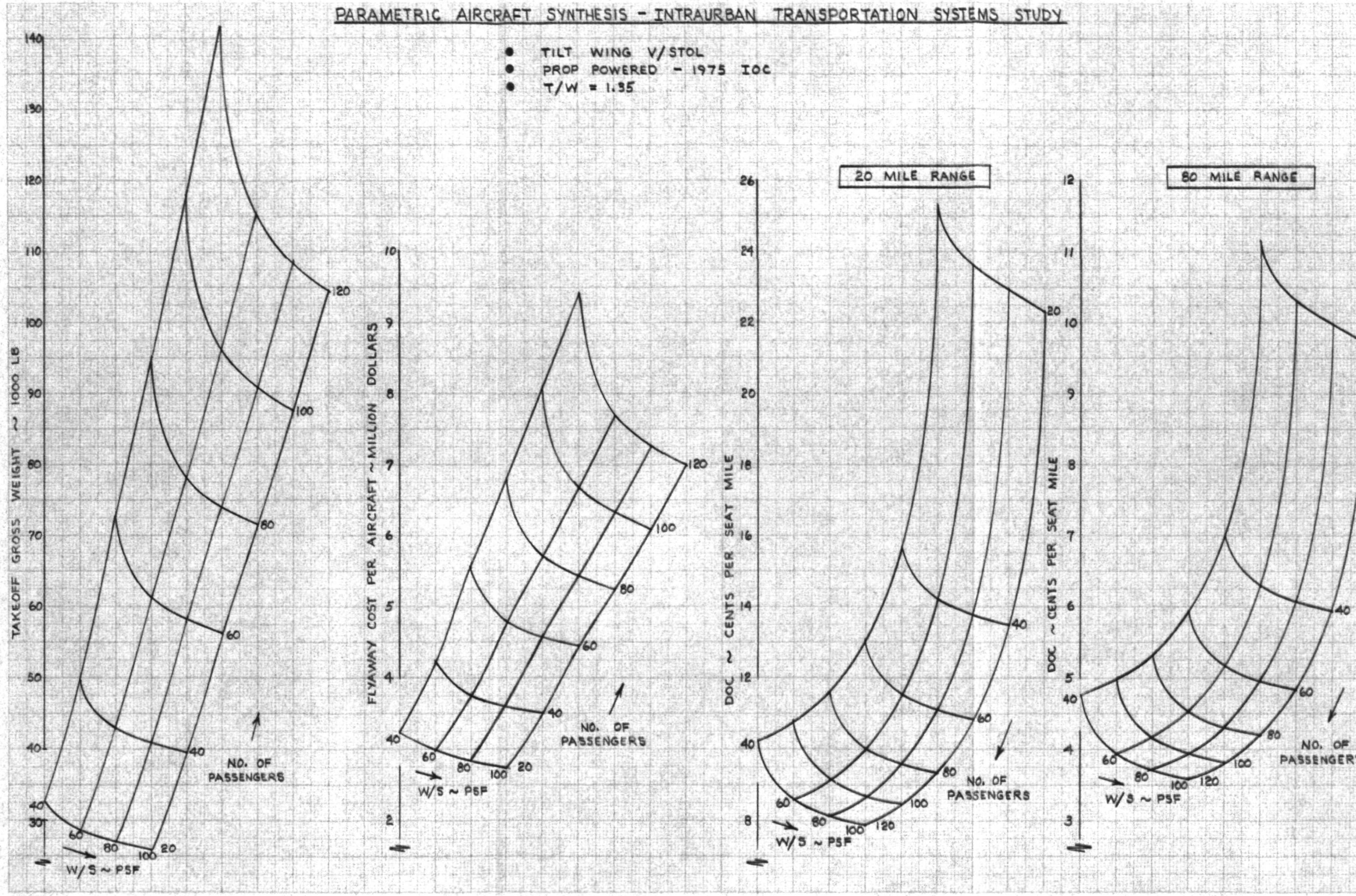

FIGURE 1.2-12. EFFECT OF WING LOADING AND PASSENGER CAPACITY ON THE 1975 TILT WING V/STOL AIRCRAFT CONCEPT

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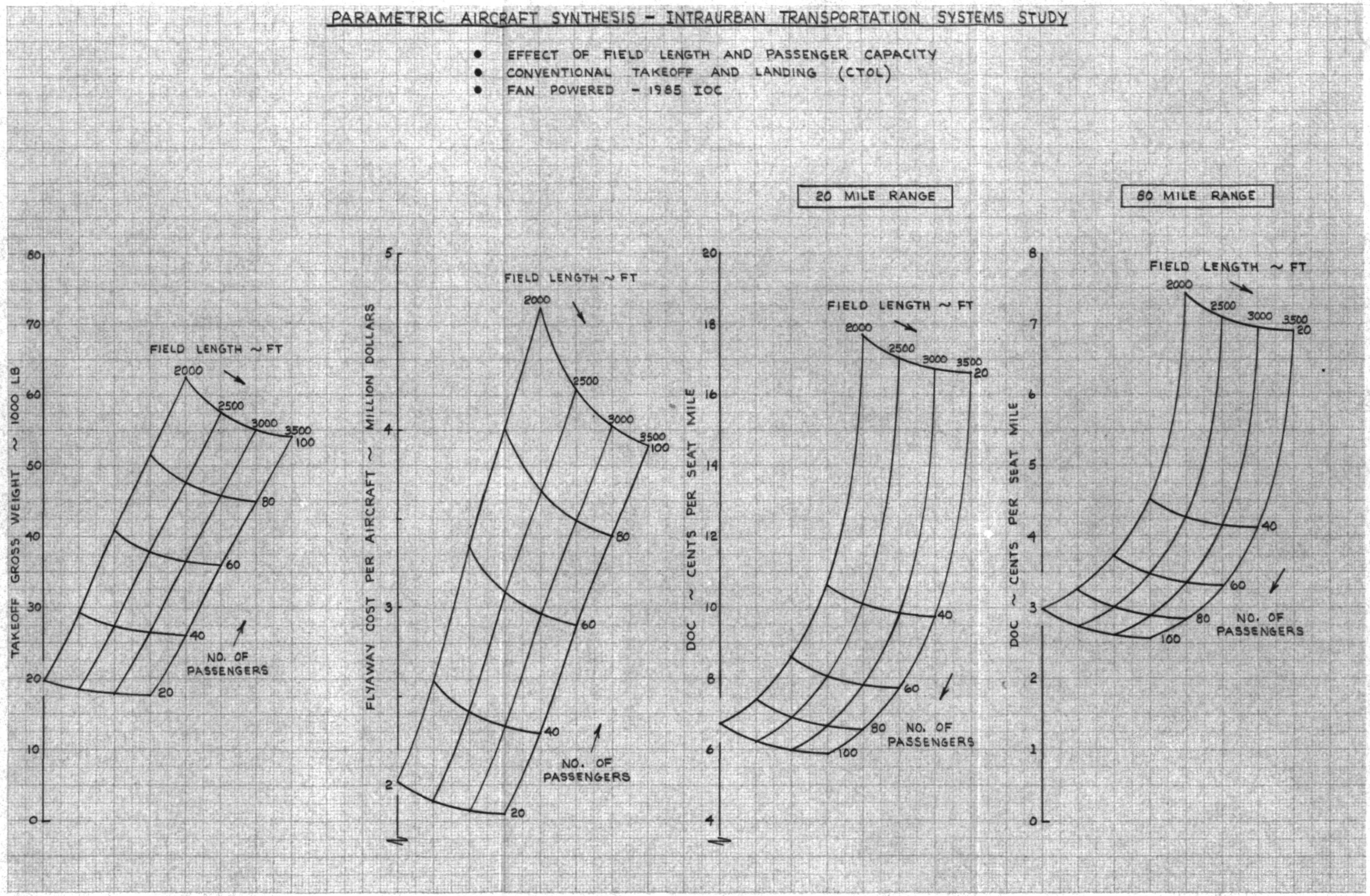

FIGURE 1.2-13. EFFECT OF FIELD LENGTH AND PASSENGER CAPACITY ON THE 1985 CTOL AIRCRAFT CONCEPT

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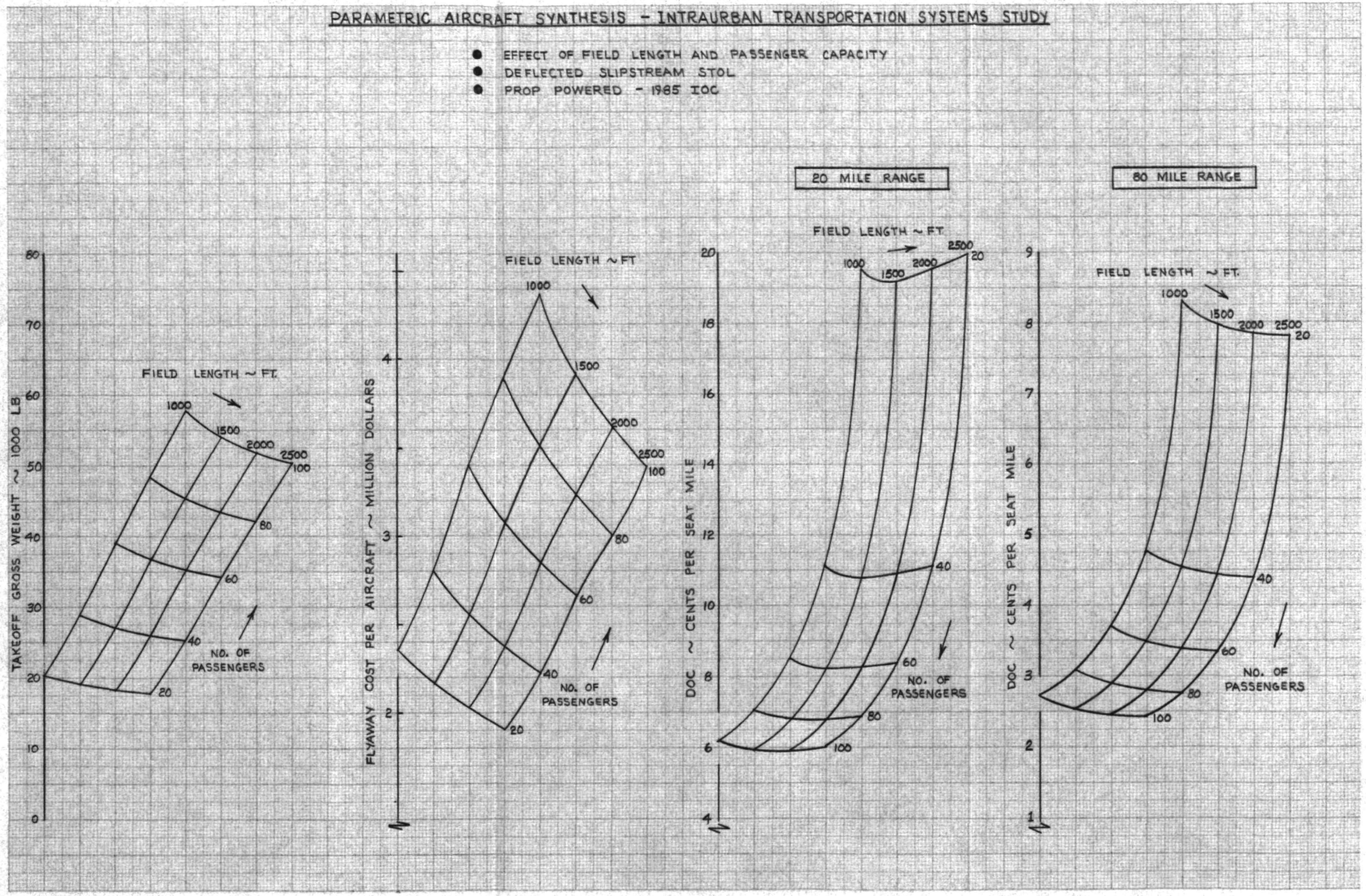

FIGURE 1.2-14. EFFECT OF FIELD LENGTH AND PASSENGER CAPACITY ON THE 1985 DEFLECTED SLIPSTREAM STOL AIRCRAFT CONCEPT

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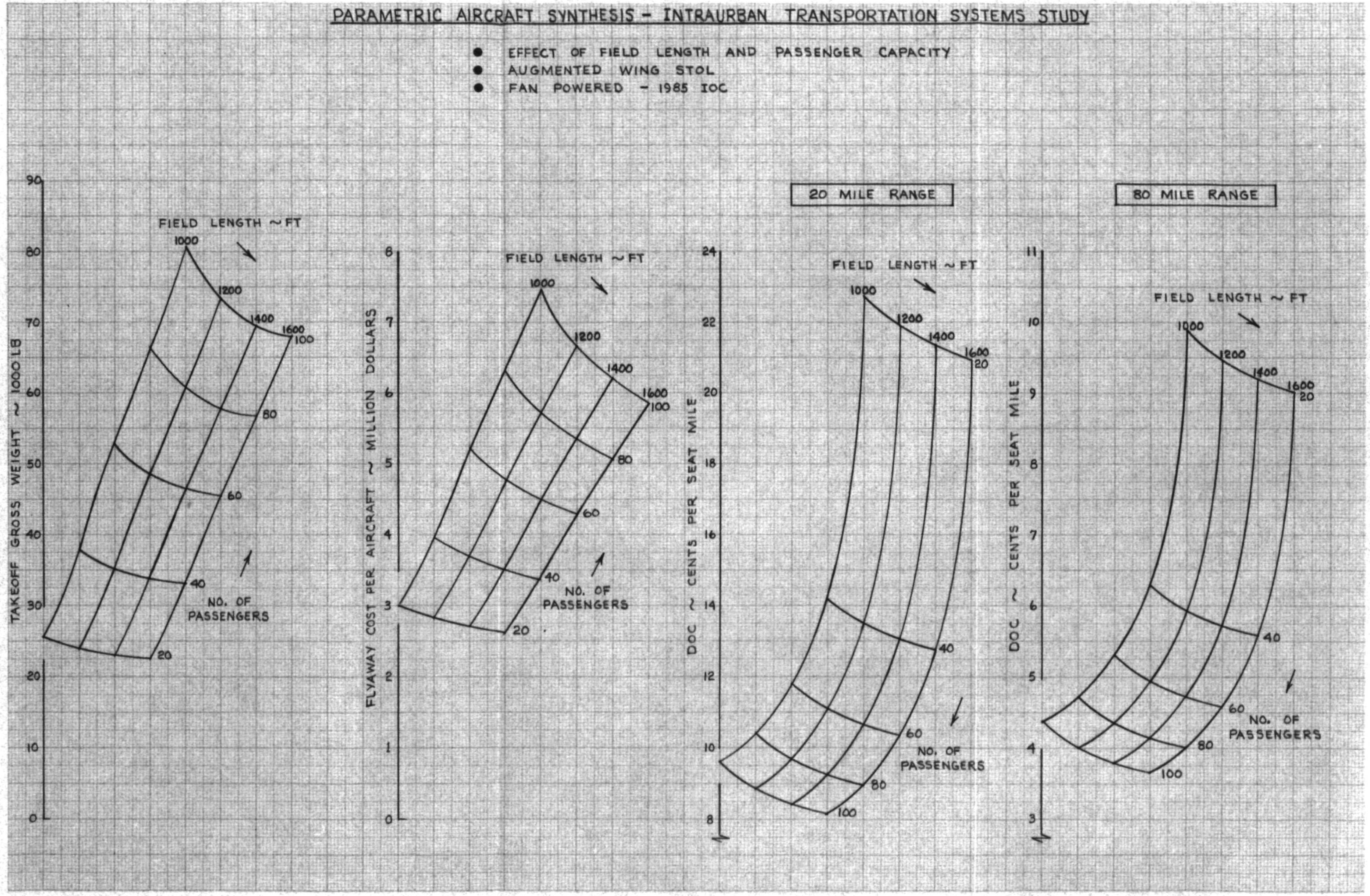

FIGURE 1.2-15. EFFECT OF FIELD LENGTH AND PASSENGER CAPACITY ON THE 1985 AUGMENTED WING STOL AIRCRAFT CONCEPT

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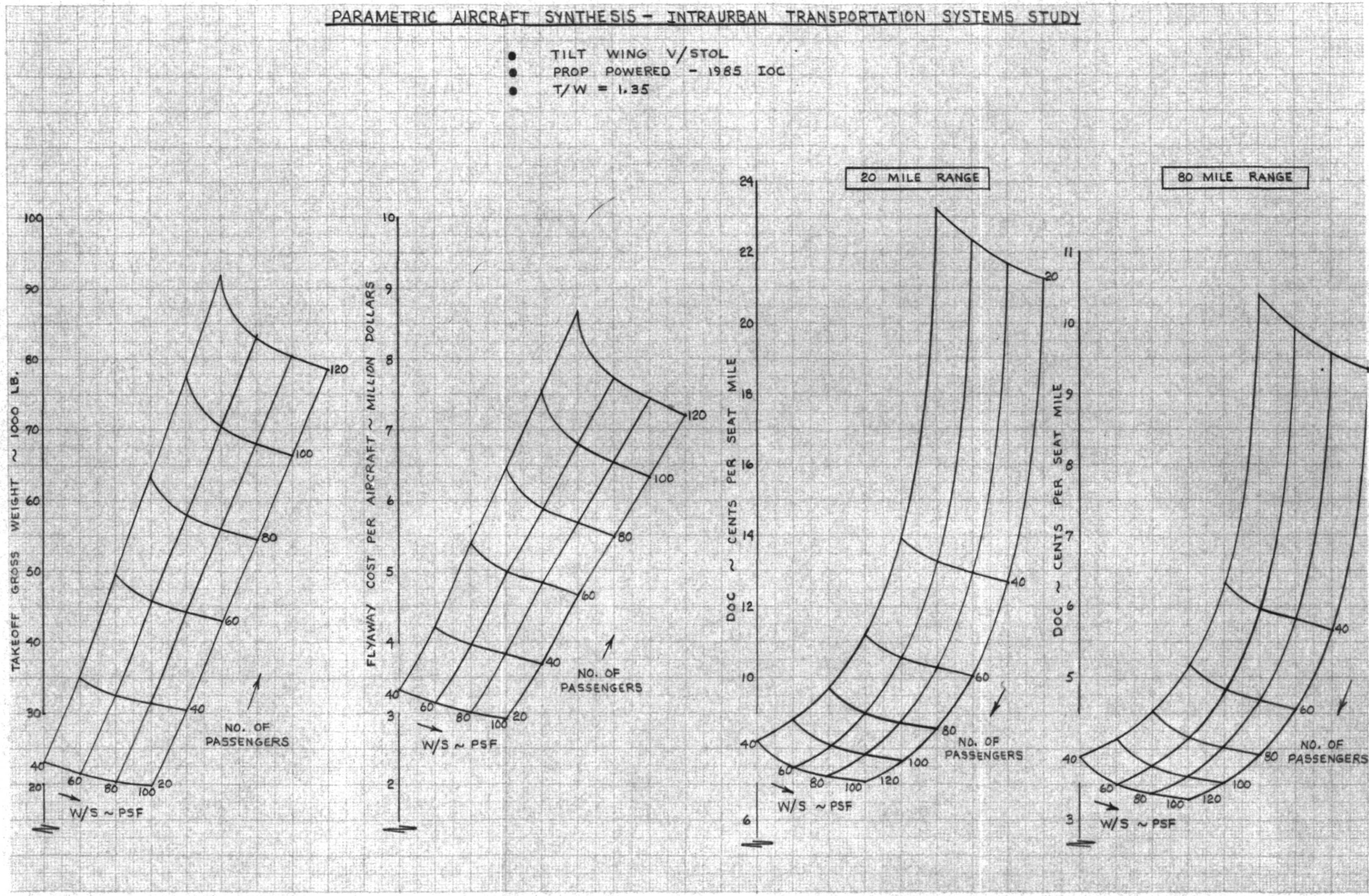

FIGURE 1.2-16. EFFECT OF WING LOADING AND PASSENGER CAPACITY ON THE 1985 TILT WING V/STOL AIRCRAFT CONCEPT

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TABLE 1.2-6 1975 IOC CTOL AIRCRAFT CHARACTERISTICS

Aircraft Concept	IOC Year	Field Length (ft)	Number of Passengers	Takeoff Gross Weight (lb)	Thrust-to-Weight Ratio	Wing Loading (psf)	Aspect Ratio	Fuel Fraction
CTOL	1975	2000	40	33,164	0.45	40.0	10.0	0.089
CTOL	1975	2000	60	46,364	0.45	40.0	10.0	0.089
CTOL	1975	2000	80	58,610	0.45	40.0	10.0	0.089
CTOL	1975	2000	100	71,417	0.45	40.0	10.0	0.089
CTOL	1975	2500	40	30,427	0.45	55.0	10.0	0.081
CTOL	1975	2500	60	42,021	0.45	55.0	10.0	0.081
CTOL	1975	2500	80	52,648	0.45	55.0	10.0	0.081
CTOL	1975	2500	100	63,607	0.45	55.0	10.0	0.081
CTOL	1975	3000	40	29,090	0.46	70.0	10.0	0.076
CTOL	1975	3000	60	40,014	0.46	70.0	10.0	0.076
CTOL	1975	3000	80	49,970	0.46	70.0	10.0	0.076
CTOL	1975	3000	100	60,153	0.46	70.0	10.0	0.076
CTOL	1975	3500	40	28,337	0.47	86.5	10.0	0.074
CTOL	1975	3500	60	38,859	0.47	86.5	10.0	0.074
CTOL	1975	3500	80	48,398	0.47	86.5	10.0	0.074
CTOL	1975	3500	100	58,134	0.47	86.5	10.0	0.074

TABLE 1.2-7 1985 IOC CTOL AIRCRAFT CHARACTERISTICS

Aircraft Concept	IOC Year	Field Length (ft)	Number of Passengers	Takeoff Gross Weight (lb)	Thrust-to-Weight Ratio	Wing Loading (psf)	Aspect Ratio	Fuel Fraction
CTOL	1985	2000	40	29,285	0.440	45.5	10.0	0.149
CTOL	1985	2000	60	40,829	0.440	45.5	10.0	0.149
CTOL	1985	2000	80	51,470	0.440	45.5	10.0	0.149
CTOL	1985	2000	100	62,429	0.440	45.5	10.0	0.149
CTOL	1985	2500	40	27,354	0.440	63.0	10.0	0.136
CTOL	1985	2500	60	37,900	0.440	63.0	10.0	0.136
CTOL	1985	2500	80	47,569	0.440	63.0	10.0	0.136
CTOL	1985	2500	100	57,453	0.440	63.0	10.0	0.136
CTOL	1985	3000	40	26,419	0.445	81.0	10.0	0.129
CTOL	1985	3000	60	36,515	0.445	81.0	10.0	0.129
CTOL	1985	3000	80	45,734	0.445	81.0	10.0	0.129
CTOL	1985	3000	100	55,103	0.445	81.0	10.0	0.129
CTOL	1985	3500	40	26,055	0.450	100.0	10.0	0.131
CTOL	1985	3500	60	35,961	0.450	100.0	10.0	0.131
CTOL	1985	3500	80	44,983	0.450	100.0	10.0	0.131
CTOL	1985	3500	100	55,089	0.450	100.0	10.0	0.131

TABLE 1.2-8 1975 IOC DEFLECTED SLIPSTREAM STOL AIRCRAFT CHARACTERISTICS

Aircraft Concept	IOC Year	Field Length (ft)	Number of Passengers	Takeoff Gross Weight (lb)	Thrust-to-Weight Ratio	Wing Loading (psf)	Aspect Ratio	Fuel Fraction
STOL (Deflected Slipstream)	1975	1000	40	34,387	0.740	60.0	8.0	0.104
	1975	1000	60	46,673	0.740	60.0	8.0	0.104
	1975	1000	80	57,794	0.740	60.0	7.0	0.104
	1975	1000	100	69,290	0.740	60.0	7.0	0.104
STOL (Deflected Slipstream)	1975	1500	40	31,519	0.525	60.0	8.0	0.097
	1975	1500	60	42,566	0.525	60.0	7.0	0.097
	1975	1500	80	52,482	0.525	60.0	6.0	0.097
	1975	1500	100	62,626	0.525	60.0	6.0	0.097
STOL (Deflected Slipstream)	1975	2000	40	30,627	0.485	67.0	8.0	0.091
	1975	2000	60	41,271	0.485	67.0	7.0	0.091
	1975	2000	80	50,831	0.485	67.0	7.0	0.091
	1975	2000	100	60,584	0.485	67.0	6.0	0.091
STOL (Deflected Slipstream)	1975	2500	40	29,742	0.430	73.0	8.0	0.087
	1975	2500	60	40,030	0.430	73.0	8.0	0.087
	1975	2500	80	49,249	0.430	73.0	7.0	0.087
	1975	2500	100	56,346	0.430	73.0	6.0	0.087

TABLE 1.2-9. 1985 IOC DEFLECTED SLIPSTREAM STOL AIRCRAFT CHARACTERISTICS

Aircraft Concept	IOC Year	Field Length (ft)	Number of Passengers	Takeoff Gross Weight (lb)	Thrust-to-Weight Ratio	Wing Loading (psf)	Aspect Ratio	Fuel Fraction
STOL (Deflected Slipstream)	1985	1000	40	28,841	0.680	60.0	8.0	0.096
	1985	1000	60	39,100	0.680	60.0	8.0	0.096
	1985	1000	80	48,377	0.680	60.0	7.0	0.096
	1985	1000	100	57,838	0.680	60.0	7.0	0.096
STOL (Deflected Slipstream)	1985	1500	40	27,439	0.530	64.0	8.0	0.090
	1985	1500	60	37,091	0.530	64.0	8.0	0.090
	1985	1500	80	45,810	0.530	64.0	7.0	0.090
	1985	1500	100	54,665	0.530	64.0	6.0	0.090
STOL (Deflected Slipstream)	1985	2000	40	26,768	0.490	76.0	10.0	0.083
	1985	2000	60	36,117	0.490	76.0	9.0	0.083
	1985	2000	80	44,574	0.490	76.0	8.0	0.083
	1985	2000	100	53,162	0.490	76.0	7.0	0.083
STOL (Deflected Slipstream)	1985	2500	40	26,445	0.500	90.0	11.0	0.080
	1985	2500	60	35,877	0.500	90.0	11.0	0.080
	1985	2500	80	44,249	0.500	90.0	10.0	0.080
	1985	2500	100	52,745	0.500	90.0	9.0	0.080

TABLE 1.2-10. 1985 IOC AUGMENTED WING STOL AIRCRAFT CHARACTERISTICS

Aircraft Concept	IOC Year	Field Length (ft)	Number of Passengers	Takeoff Gross Weight (lb)	Thrust-to-Weight Ratio	Wing Loading (psf)	Aspect Ratio	Fuel Fraction
STOL (Augmented Wing)	1985	1000	40	38,934	0.645	60.0	8.0	0.180
	1985	1000	60	53,928	0.645	60.0	8.0	0.180
	1985	1000	80	67,829	0.645	60.0	8.0	0.180
	1985	1000	100	82,138	0.645	60.0	8.0	0.180
STOL (Augmented Wing)	1985	1500	40	33,227	0.605	100.0	8.0	0.160
	1985	1500	60	45,609	0.605	100.0	8.0	0.160
	1985	1500	80	56,977	0.605	100.0	8.0	0.160
	1985	1500	100	68,521	0.605	100.0	8.0	0.160
STOL (Augmented Wing)	1985	2000	40	31,544	0.535	100.0	8.0	0.150
	1985	2000	60	43,326	0.535	100.0	8.0	0.150
	1985	2000	80	54,105	0.535	100.0	8.0	0.150
	1985	2000	100	65,092	0.535	100.0	8.0	0.150
STOL (Augmented Wing)	1985	2500	40	30,430	0.485	100.0	8.0	0.140
	1985	2500	60	41,770	0.485	100.0	8.0	0.140
	1985	2500	80	52,190	0.485	100.0	8.0	0.140
	1985	2500	100	62,764	0.485	100.0	8.0	0.140

TABLE 1.2-11. 1975 IOC TILT WING V/STOL AIRCRAFT CHARACTERISTICS

Aircraft Concept	IOC Year	Field Length (ft)	Number of Passengers	Takeoff Gross Weight (lb)	Thrust-to-Weight Ratio	Wing Loading (psf)	Aspect Ratio	Fuel Fraction
V/STOL (Tilt Wing)	1975	150	40	49,618	1.35	40	5.0	0.147
	1975	150	60	72,677	1.35	40	5.0	0.147
	1975	150	80	94,412	1.35	40	5.0	0.147
	1975	150	100	117,947	1.35	40	5.0	0.147
V/STOL (Tilt Wing)	1975	150	40	42,870	1.35	60	7.0	0.128
	1975	150	60	61,199	1.35	60	7.0	0.128
	1975	150	80	78,082	1.35	60	7.0	0.128
	1975	150	100	96,131	1.35	60	7.0	0.128
V/STOL (Tilt Wing)	1975	150	40	40,995	1.35	80	10.0	0.120
	1975	150	60	58,193	1.35	80	10.0	0.120
	1975	150	80	73,959	1.35	80	9.0	0.120
	1975	150	100	90,710	1.35	80	9.0	0.120
V/STOL (Tilt Wing)	1975	150	40	39,523	1.35	100	11.0	0.119
	1975	150	60	56,234	1.35	100	11.0	0.119
	1975	150	80	71,624	1.35	100	11.0	0.119
	1975	150	100	87,602	1.35	100	11.0	0.119

TABLE 1.2-12 1985 IOC TILT WING V/STOL AIRCRAFT CHARACTERISTICS

Aircraft Concept	IOC Year	Field Length (ft)	Number of Passengers	Takeoff Gross Weight (lb)	Thrust-to Weight Ratio	Wing Loading (psf)	Aspect Ratio	Fuel Fraction
V/STOL (Tilt Wing)	1985	150	40	34,919	1.35	40	5.0	0.140
	1985	150	60	49,547	1.35	40	5.0	0.140
	1985	150	80	63,241	1.35	40	5.0	0.140
	1985	150	100	77,403	1.35	40	5.0	0.140
V/STOL (Tilt Wing)	1985	150	40	32,418	1.35	60	8.0	0.123
	1985	150	60	45,678	1.35	60	8.0	0.123
	1985	150	80	57,724	1.35	60	7.0	0.123
	1985	150	100	70,186	1.35	60	7.0	0.123
V/STOL (Tilt Wing)	1985	150	40	31,499	1.35	80	11.0	0.115
	1985	150	60	44,333	1.35	80	10.0	0.115
	1985	150	80	55,968	1.35	80	10.0	0.115
	1985	150	100	67,921	1.35	80	10.0	0.115
V/STOL (Tilt Wing)	1985	150	40	30,413	1.35	100	11.0	0.113
	1985	150	60	42,888	1.35	100	11.0	0.113
	1985	150	80	54,412	1.35	100	11.0	0.113
	1985	150	100	66,169	1.35	100	11.0	0.113

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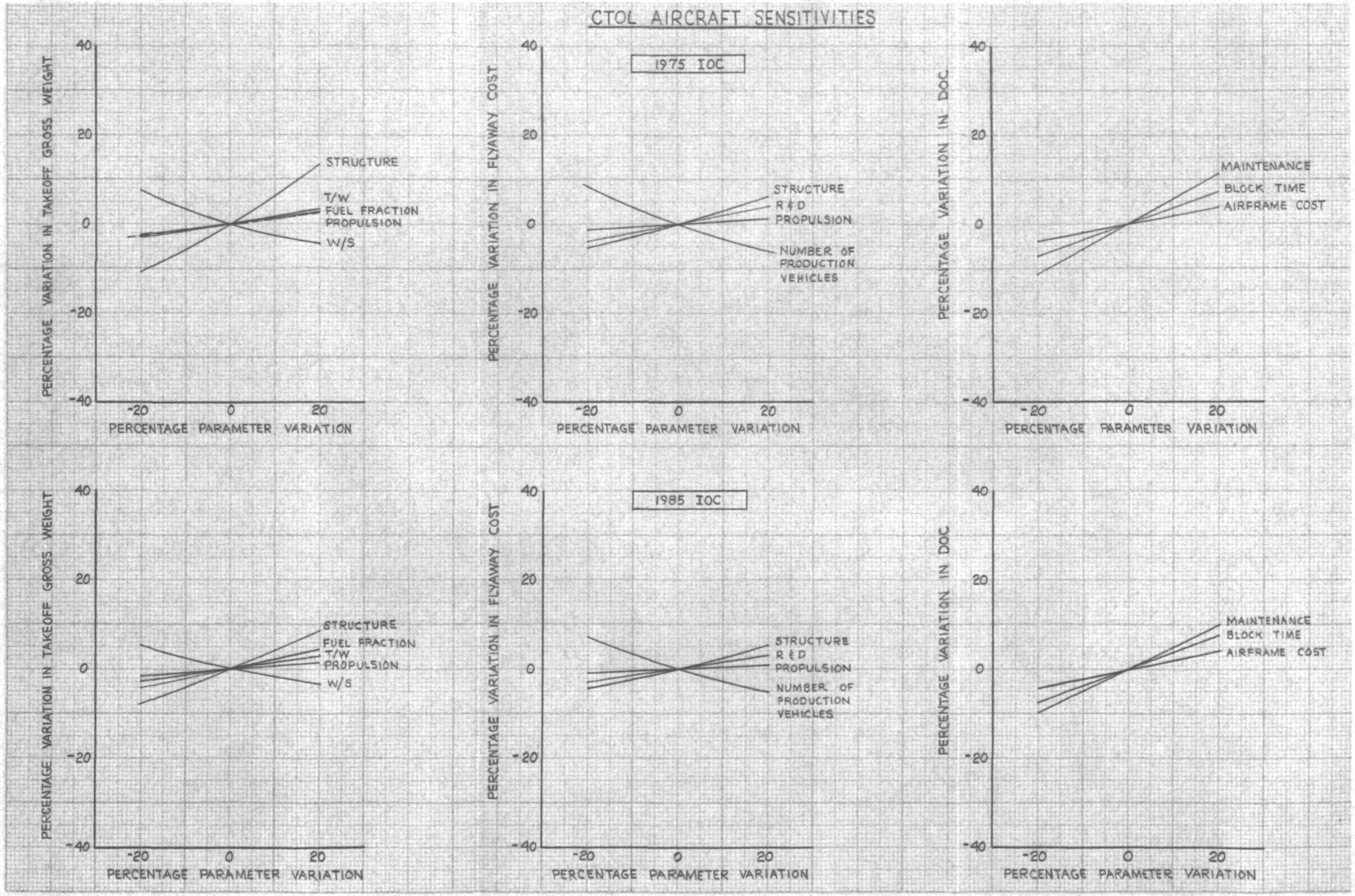

FIGURE 1.2-17. CTOL AIRCRAFT SENSITIVITIES

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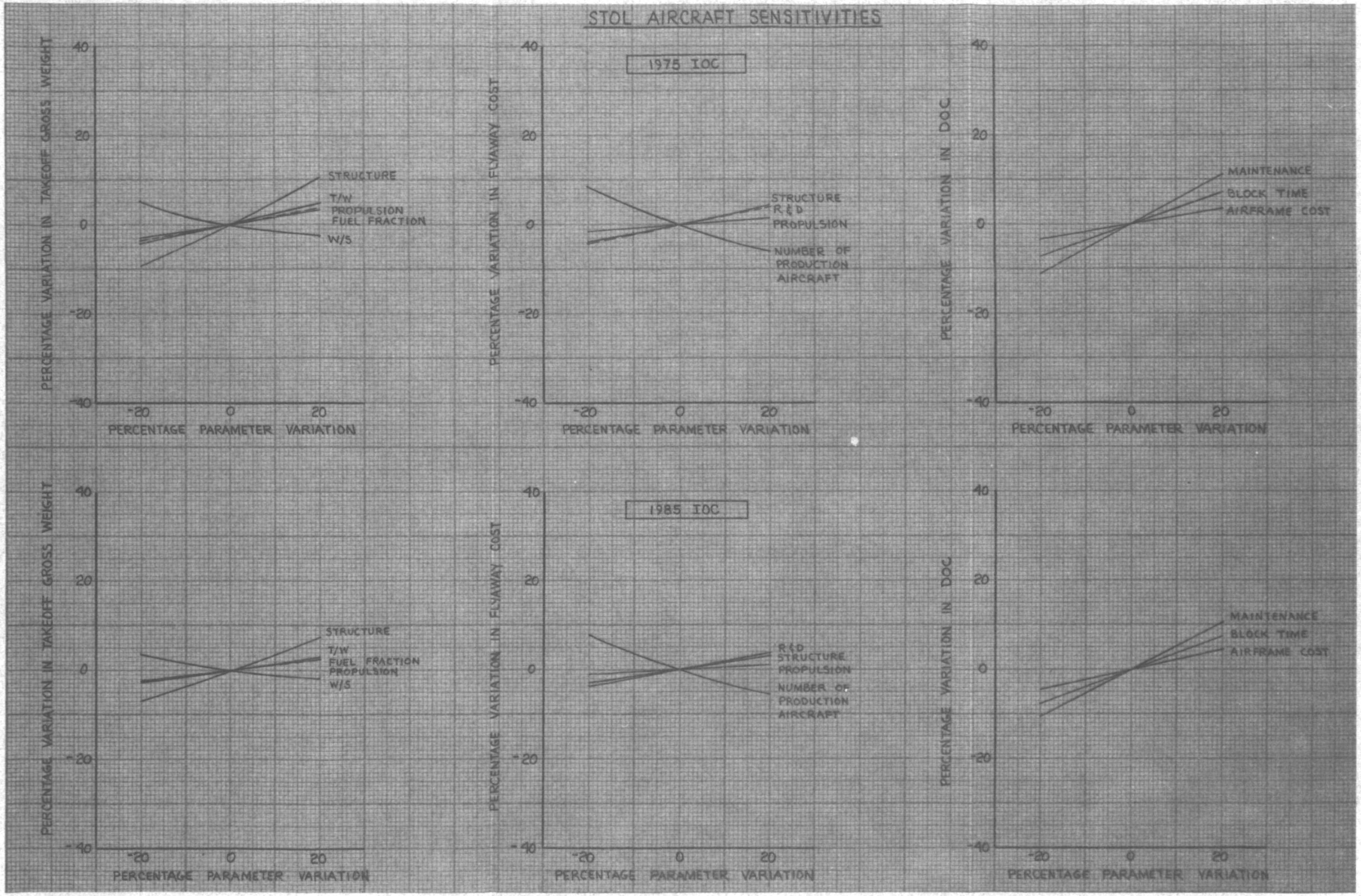

FIGURE 1.2-18. STOL DEFLECTED SLIPSTREAM AIRCRAFT SENSITIVITIES

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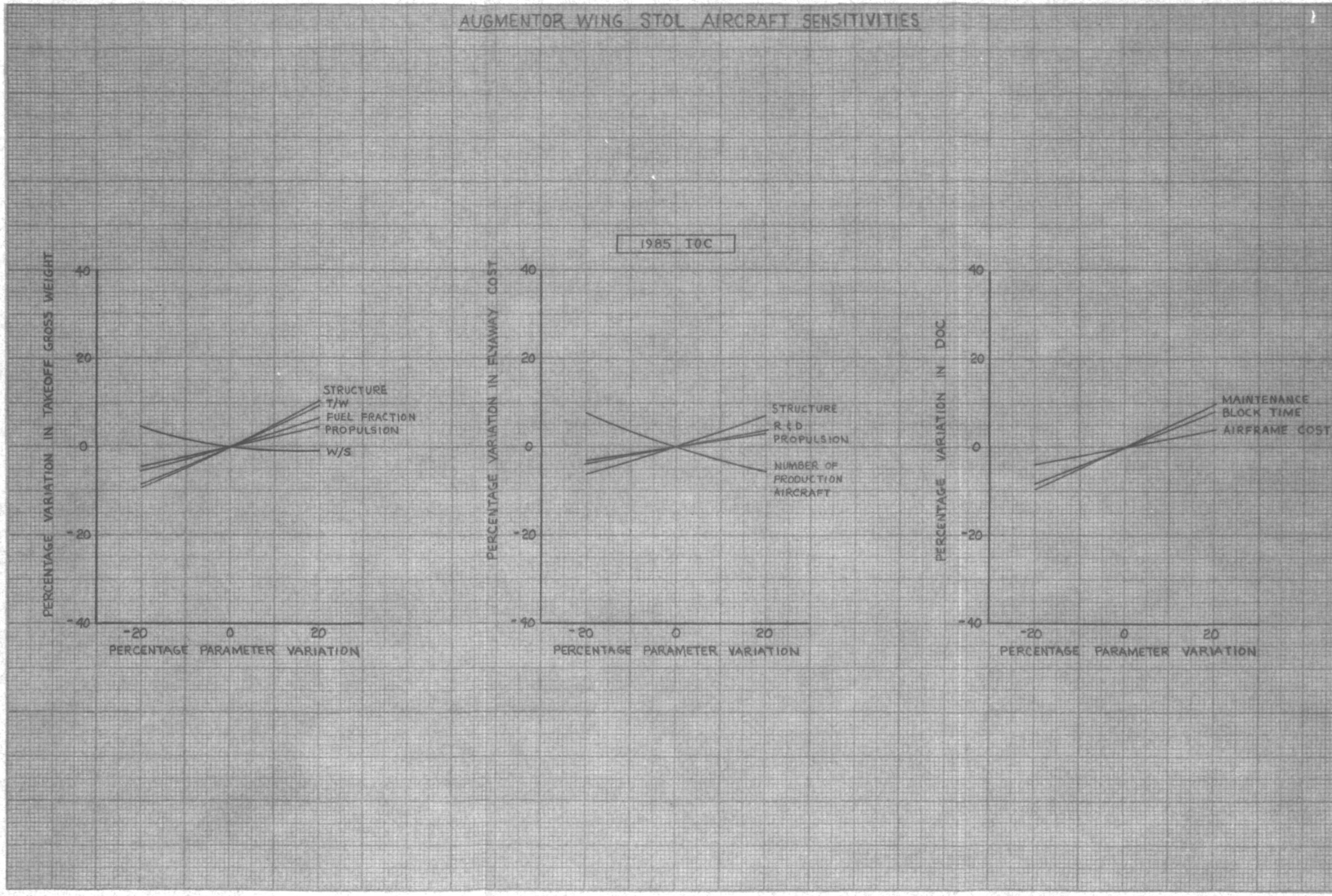

FIGURE 1.2-19. STOL (AUGMENTOR WING) AIRCRAFT SENSITIVITIES

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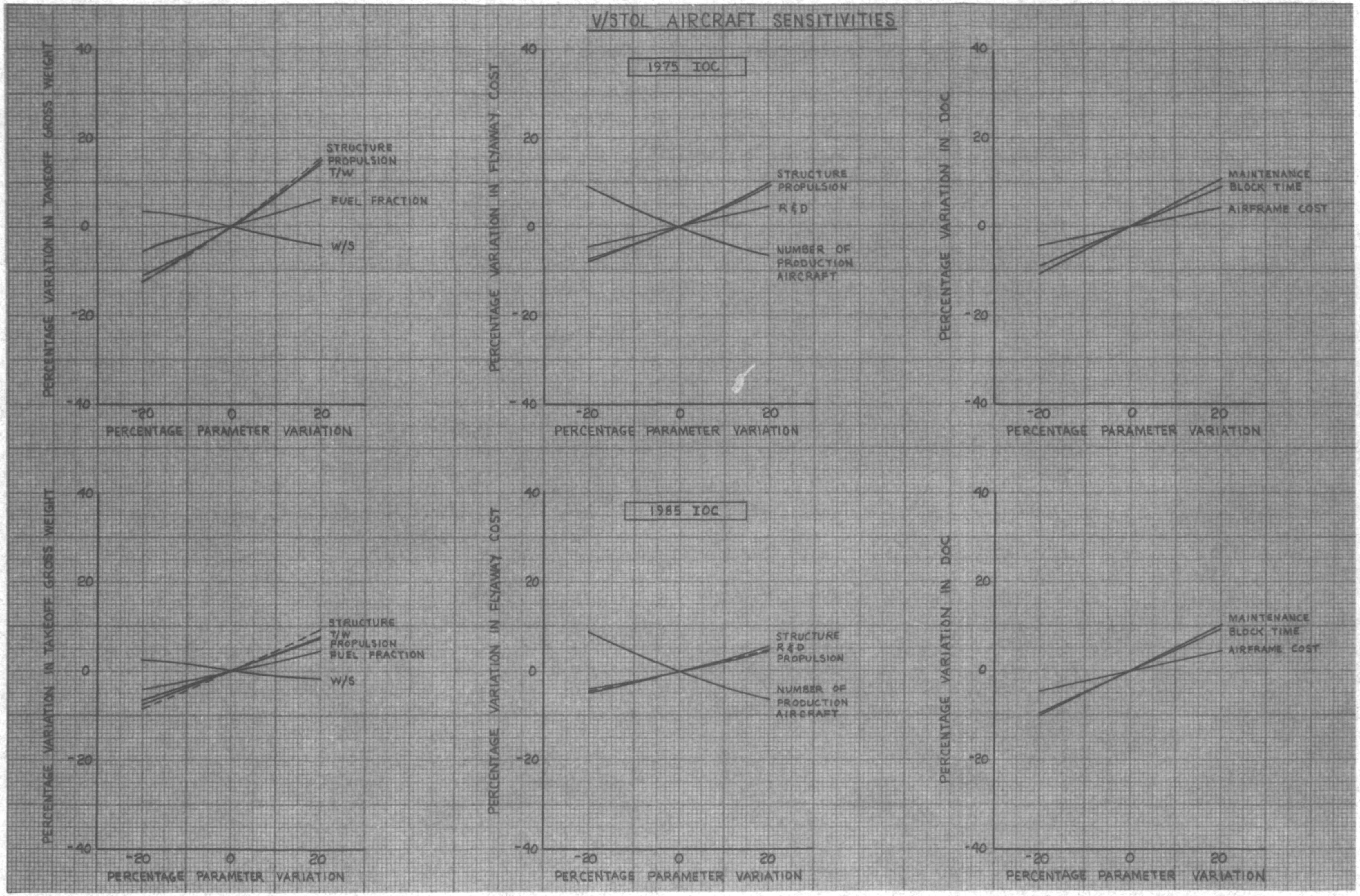

FIGURE 1.2-20. VTOL (TILT WING) AIRCRAFT SENSITIVITIES

1.2.2 OPERATIONAL REQUIREMENTS

The objective of this task was to identify the operational requirements for an intraurban air transportation system in the Detroit region. Originally, Lockheed had planned to develop several alternative route and schedule plans for each of the candidate aircraft concepts in order to arrive at daily utilization rates and fleet size requirements. This approach, however, was inconsistent with the parametric theme of the Phase I analysis. In order to establish the base utilization rate and fleet size, Lockheed assumed that an aircraft would make 7 passenger-carrying flights and 2 maintenance/service/fueling flights per 3-hour period.

1.2.2.1 Minimum Load Factor

In order to establish routes and fleet size requirements, Lockheed considered the range of 50 - 100 percent for minimum load factor criteria.

The minimum load factor criteria in conjunction with aircraft capacity data was used to identify candidate zone-pairs for routes (more specifically to eliminate those zone-pairs that could not support at least one (1) flight).

To establish fleet size requirements, Lockheed assumed that the intraurban system would always fly the maximum number of flights, as determined by demand, aircraft capacity, and minimum load factor, in order to maximize frequency of service.

1.2.2.2 Frequency of Service

Of critical importance to the success of any public transportation system is its ability to provide attractive frequencies of service (expressed in terms of flights per unit of time, or in terms of time between flight) over its route network throughout the day, and especially during the peak periods. Classically frequency of service is treated as an independent variable contributing to the determination of market demand. In the subject study, Lockheed, with NASA concurrence, elected to fix demand over a range of 10 - 30 percent of the traffic volume, and to set minimum load factor constraints (50 - 100 percent). As a result frequency

of service became a dependent variable determined by demand, aircraft passenger capacity and minimum load factor.

Frequency of service is one of the factors which determines where along the demand capture range (10 - 30 percent) any particular aircraft system's actual demand would fall.

1.2.2.3 Fare

For the purpose of the Phase I analysis fare is calculated for all aircraft concepts by the equation

$$\text{FARE} = 1.15\,(\text{TSC} - \text{SUBSIDY})/\text{PASSENGERS SERVED}$$

Because only comparisons between aircraft concepts are being established, fares have not been adjusted to make them competitive with those of other transportation systems.

1.3 SYNTHESIS AND OPTIMIZATION

1.3.1 TOTAL SYSTEM SYNTHESIS

Total system synthesis consist of combining the data developed for each of the candidate aircraft concepts with those data generated in the Market Scenario, Transportation Complement and Operational Requirements, and results from the cost analysis (DOC and IOC) to synthesize the total intra-urban air transportation systems.

Figure 1.3-1 is a basic summary block flow diagram of the total system synthesis. For each aircraft concept, the optimum vehicle is matched with the total transportation system characteristics such as to determine the best fleet size, aircraft size (passenger capacity), terminal size, total system cost, fare and schedule frequency. This is only an overall illustrative flow diagram and does not show all of the necessary internal cross feed links and feedback loops required in this type of total system synthesis.

Total system cost (TSC) and fares are the primary variables calculated and used to do concept comparison. Preliminary interpretation of the data generated shows a number of interesting trends among the various concepts. Figure 1.3-2 is a sample printout of the total system summary. The makeup of the DOC, IOC, and TSC is shown in dollars and percentage of their respective totals.

Figure 1.3-3 presents a typical plot showing the relationships among fare, TSC and aircraft capacity for three aircraft concepts (STOL) in the 1985 time frame. Preliminary interpretation of these data suggests that, based on TSC and fare, the deflected slipstream (D.S.) concept is the most attractive of the three fixed wing STOL concepts for 1985. This trend remains consistent for all scenarios.

Figure 1.3-4 presents a typical plot showing the TSC, fare and passenger capacity relationships for a single concept in the 1985 time frame. For all aircraft studied to date there is a trend for TSC to decrease as aircraft capacity increases (over the 40-100 passenger range). In considering fare, however, Lockheed has noted a tendency for the curve to "bucket" in the 60-80 passenger capacity range for 10% demand projections. Furthermore, this bucket becomes more pronounced as minimum load factor approaches 100%. The

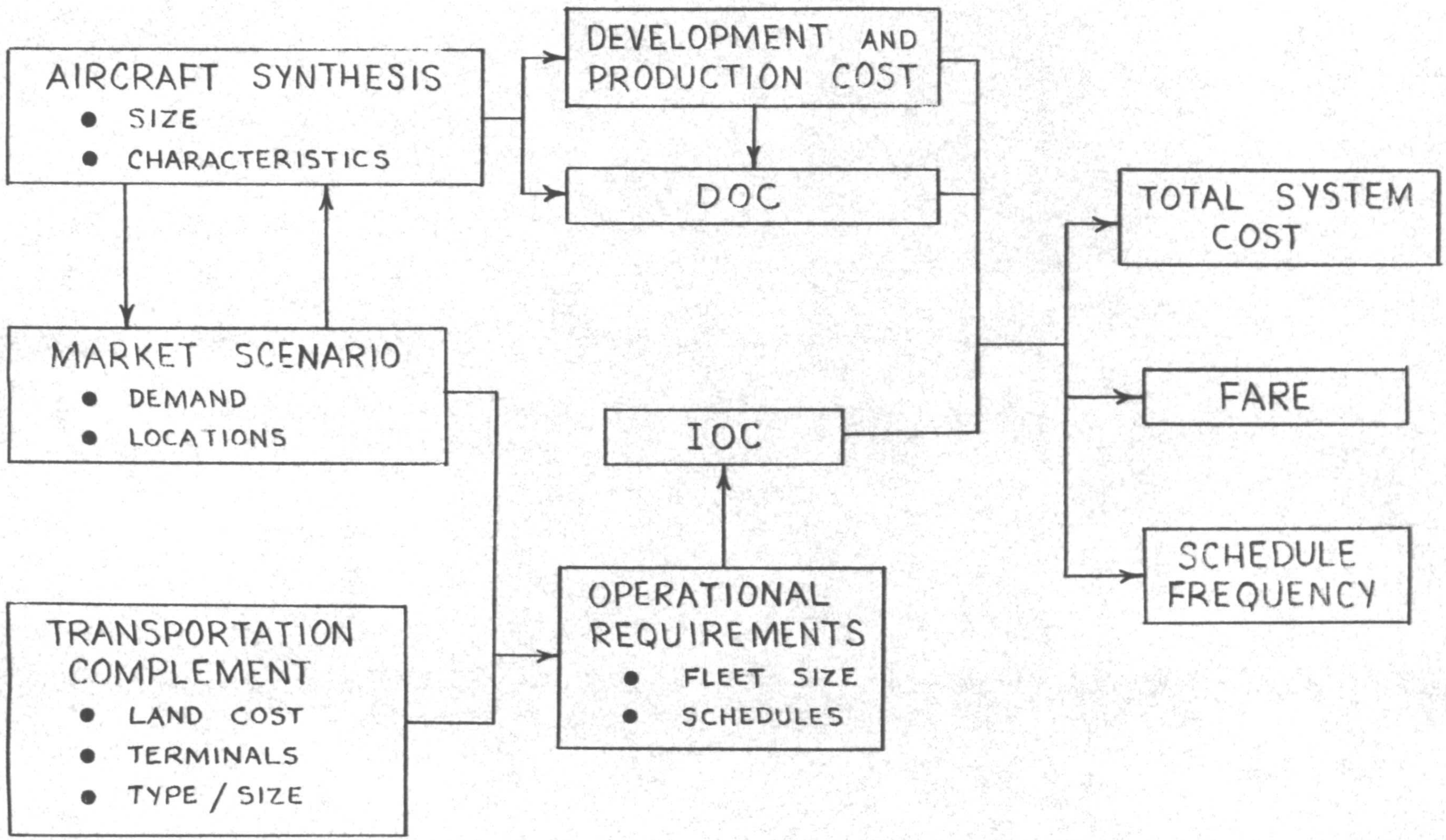

Figure 1.3.1 Total System Synthesis Flow Diagram

```
                 ROTARY WING  80 PASSENGER  AUTOGYRO - 1985 (2000 FT)          CASE  NO.  1

                                        SYSTEM   SUMMARY

            PERCENT MARKET DEMAND       30.00             AIRPORT FIELD LENGTH          2500.00
            MINIMUM LOAD   FACTOR       75.00             AIRCRAFT PASS. CAPACITY         80.00


DIRECT OPERATING COSTS - 1000 $/YR/AC    INDIRECT OPERATING COSTS - 1000 $/YR/AC      TOTAL SYSTEM COSTS - MILLIONS $

FLIGHT CREW          71.543     5.03   FACILITIES  DEPR.       110.601   12.29   PURCHASE COST OF AC      51.629    12.16
FUEL AND OIL         58.685     4.13   PERSONNEL               253.084   28.13   PURCH. COST OF SPARES    10.103     2.38
INSURANCE           104.250     7.33   OTHER EXPENSE           362.374   40.28   PURCH. COST OF FACIL.    31.862     7.51
DEPRECIATION        354.312    24.93   FACIL. MAINT            128.810   14.32   PURCH. COST OF EQUIP.     1.102     0.26
MAINTENANCE         832.603    58.58   FACIL. MAINT BURD.       38.643    4.30   OPER. COST OF AC        190.245    44.81
                                       GR. EQU. DEPR.            6.181    0.69   OPER. COST OF FACIL.    139.582    32.88
                              100.00                                    100.00                                     100.00

   TOTAL  DOC (1000 $/YR/AC)  1421.354   TOTAL IOC (1000 $/YR/AC)      899.694    TOTAL  SYSTEM  COST              424.523
   TOTAL  DOC ($/MILE/AC)        7.739   TOTAL IOC ( $/MILE/AC)          4.899


            AVERAGE TRIP RANGE - MILES           19.78        RDTE    MILLIONS $               193.50
            ANNUAL MILE DISTANCE             2728740.00       DELTA  RDTE  - MILLIONS $        193.50
            ANNUAL PASSENGER TOTAL           9639650.00       FARE - DOLLARS                     4.22
            ANNUAL NUMBER OF FLIGHTS          154830.88       REVENUE   - MILLIONS $           488.20
            AVERAGE LOAD FACTOR                   0.78        SUBSIDIES (TOTAL) - MIL. $         0.0
            NO. OF AIRCRAFT IN FLEET             14.86        SUBS. FACILITIES  - MIL. $         0.0
            UTILIZATION - ANNUAL HRS.          2518.83        SUBS. DEVELOPMENT - MIL. $         0.0
                                                              SUBS. GENERAL     - MIL. $         0.0
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Figure 1.3-2 Sample Printout of Total System Synthesis Summary

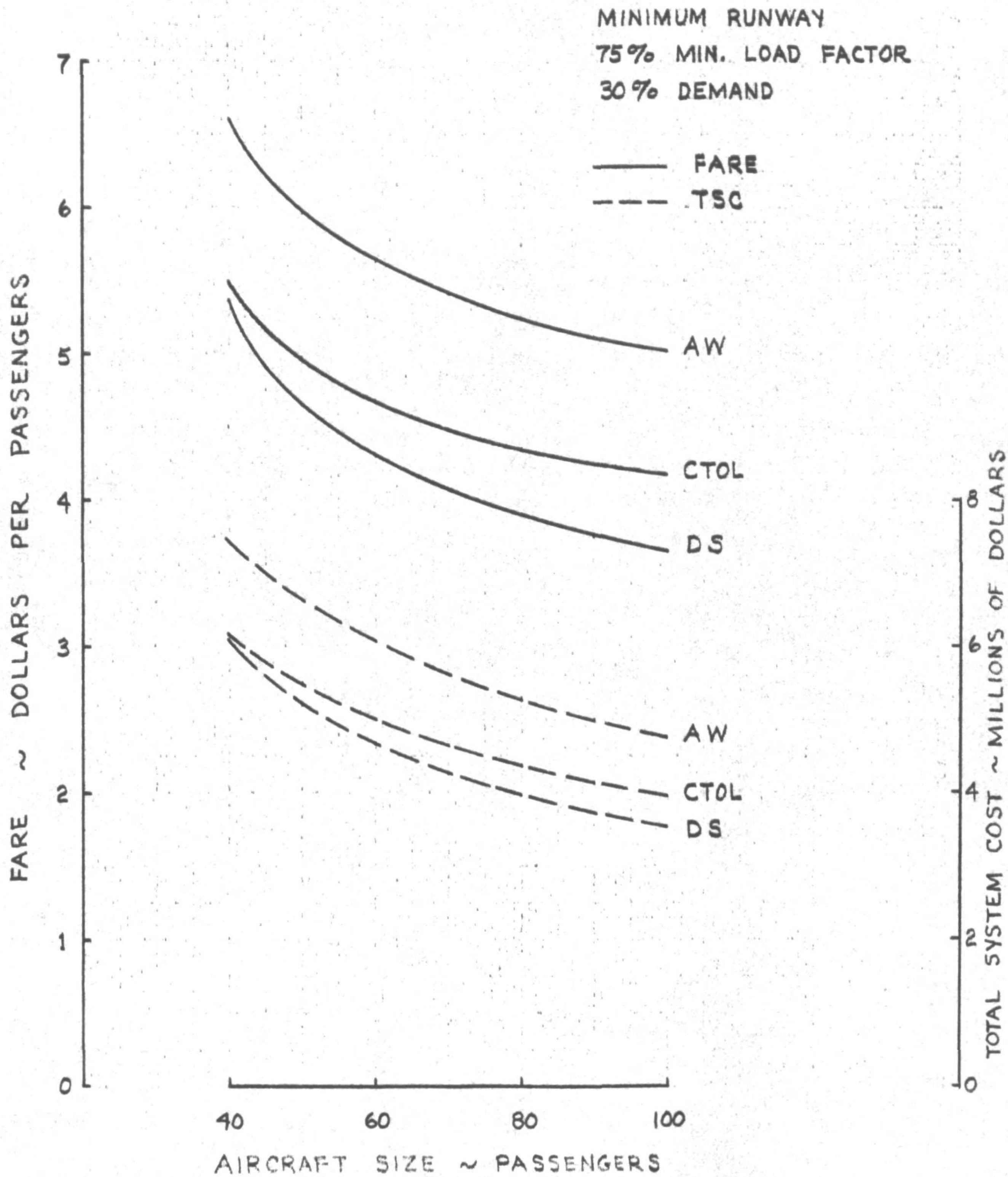

Figure 1.3.3 1985 Concept Comparison - Fare and TSC Vs. Aircraft Size

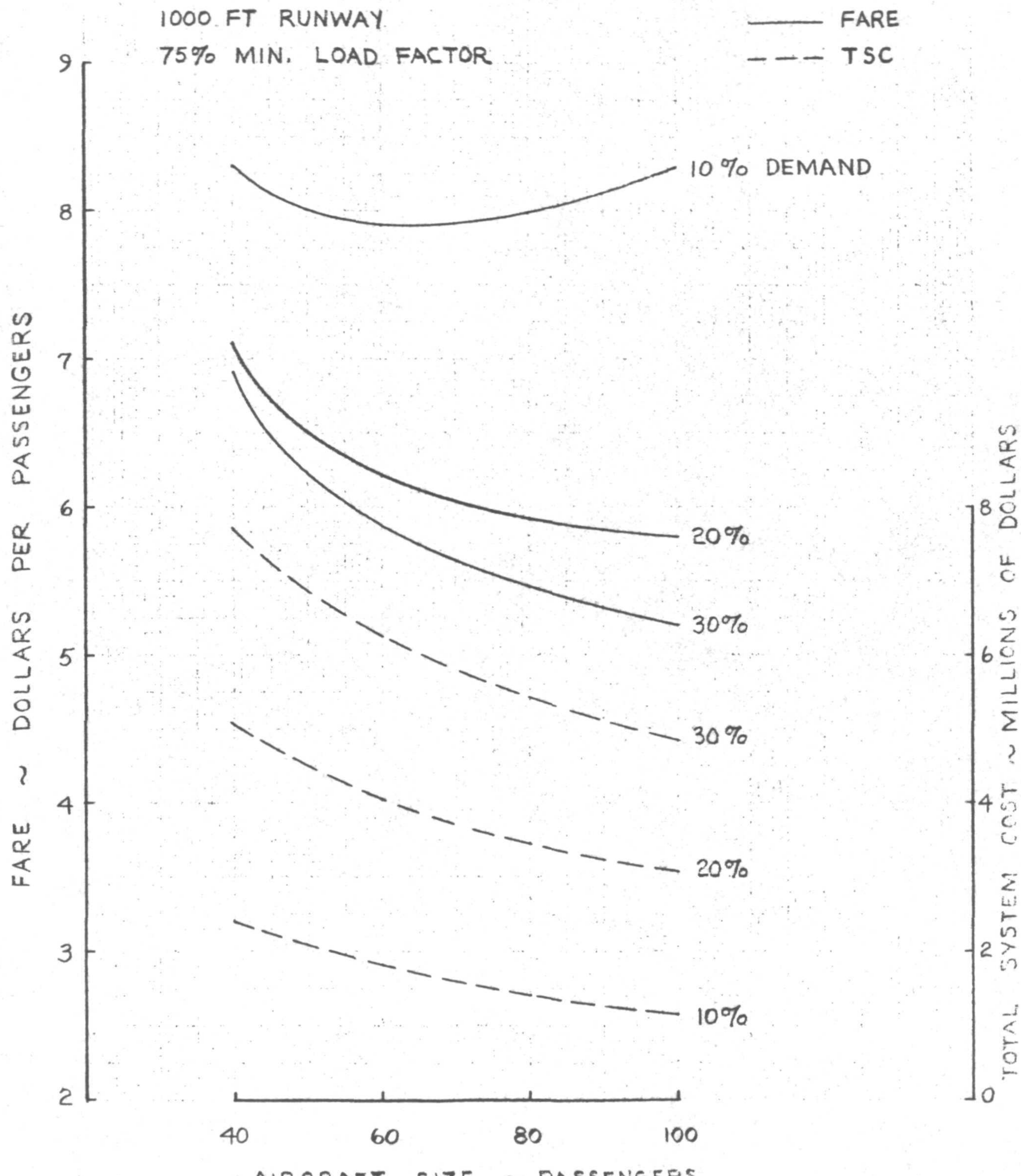

FIGURE 1.3-4. 1985 Augmented Wing STOL - Fare and TSC vs. Aircraft Size

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1.3.1.1 Selected Concept Characteristics

The effect of variations in runway field length in the 1975 time period in terms of takeoff gross weight and total system cost for each of the approach concepts is shown on Figure 1.3-5. This data is only good for 20% passenger demand, 75% minimum load factor and aircraft size of 80 passengers as noted on the figure. Increasing the field length for the CTOL and STOL (D.S.) reduces the takeoff gross weight but shows little or no change in the total system cost.

It appears that the minimum TSC for the CTOL concept occurs at approximately a runway length of 2500 feet and between 1500 to 2000 feet for the STOL (D.S.) Using a runway length of 1500 feet for the deflected slipstream STOL and 2500 feet for the CTOL concept, the effect of aircraft size is investigated as shown on Figure 1.3-6. The TSC goes down as the aircraft size is increased to 100 passengers due to the reduction in the total fleet size, but from a fare standpoint, as the aircraft size increases the fare does not continue to reduce for all of the approach concepts. This effect is due to the fact that as aircraft size is increased, fewer total passengers are served due to the minimum load factor criteria. Thus the TSC or fare is spread over a fewer number of people which results in a higher fare per person. This effect is dampened by the TSC going down with increase passenger size.

The tilt wing VTOL concept shows a steady decrease in fare with increased aircraft size whereas the deflected slipstream STOL shows little or no advantage in increasing the aircraft size beyond 70 passengers from a minimum fare standpoint. The CTOL concept has a minimum fare optimum at 70 passengers. Figure 1.3-7 presents the aircraft concepts in the 1985 technology time period. The effect of field length variation on the takeoff gross weight and TSC for a 20% passenger served demand, 75% minimum load factor criteria and an aircraft aircraft size of 80 passengers. The deflected slipstream STOL, augmentor wing STOL and CTOL concepts show a weight advantage by increasing the field length whereas the autogyro shows no weight advantage by increasing the field length beyond 2000 feet. From the TSC standpoint, the deflected slipstream STOL indicates an optimum (minimum TSC) at a

FIELD LENGTH EFFECT

1975 TECHNOLOGY

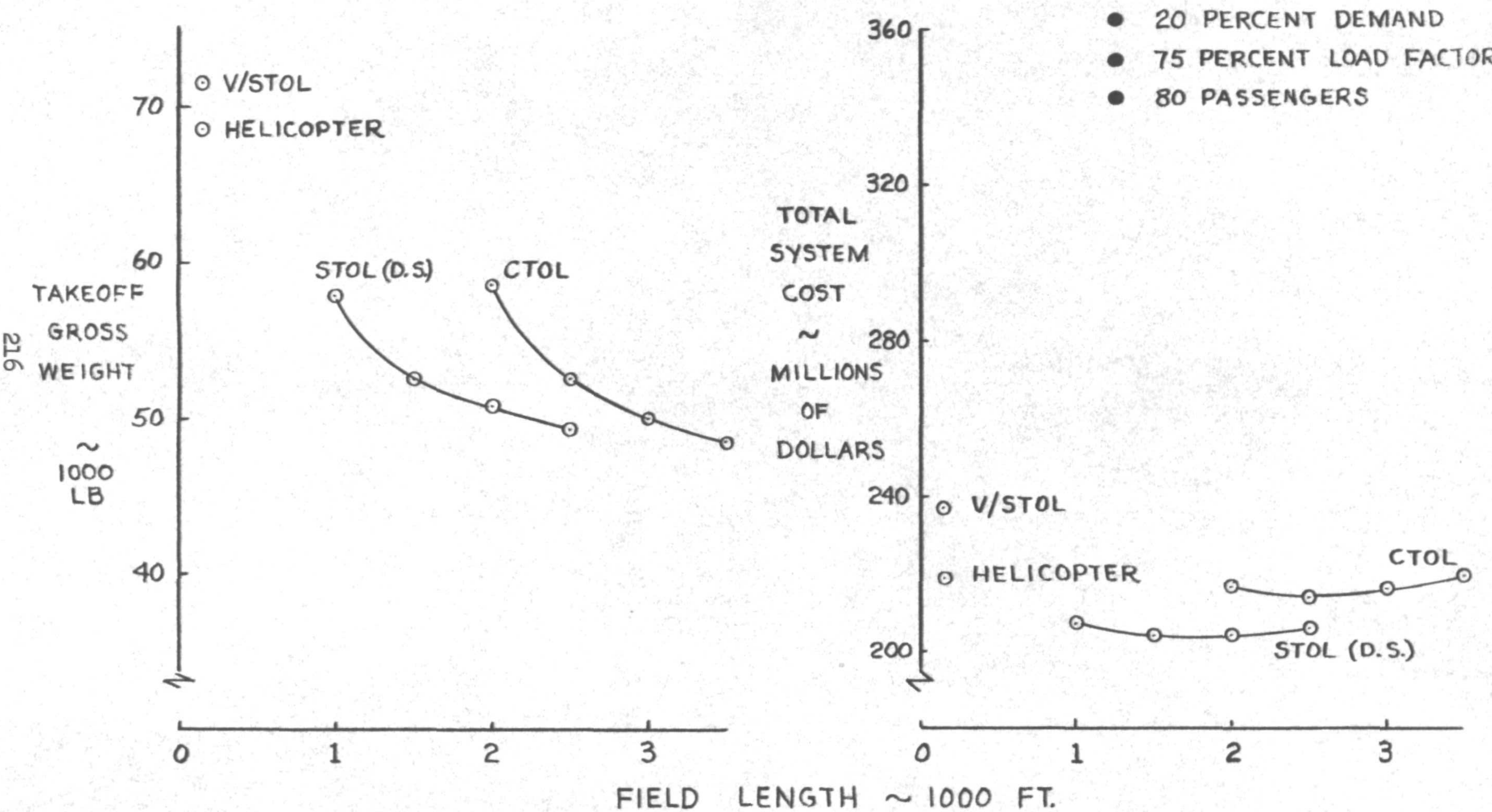

Figure 1.3-5 1975 Concept Comparison - Takeoff Gross Weight and TSC Vs. Field Length

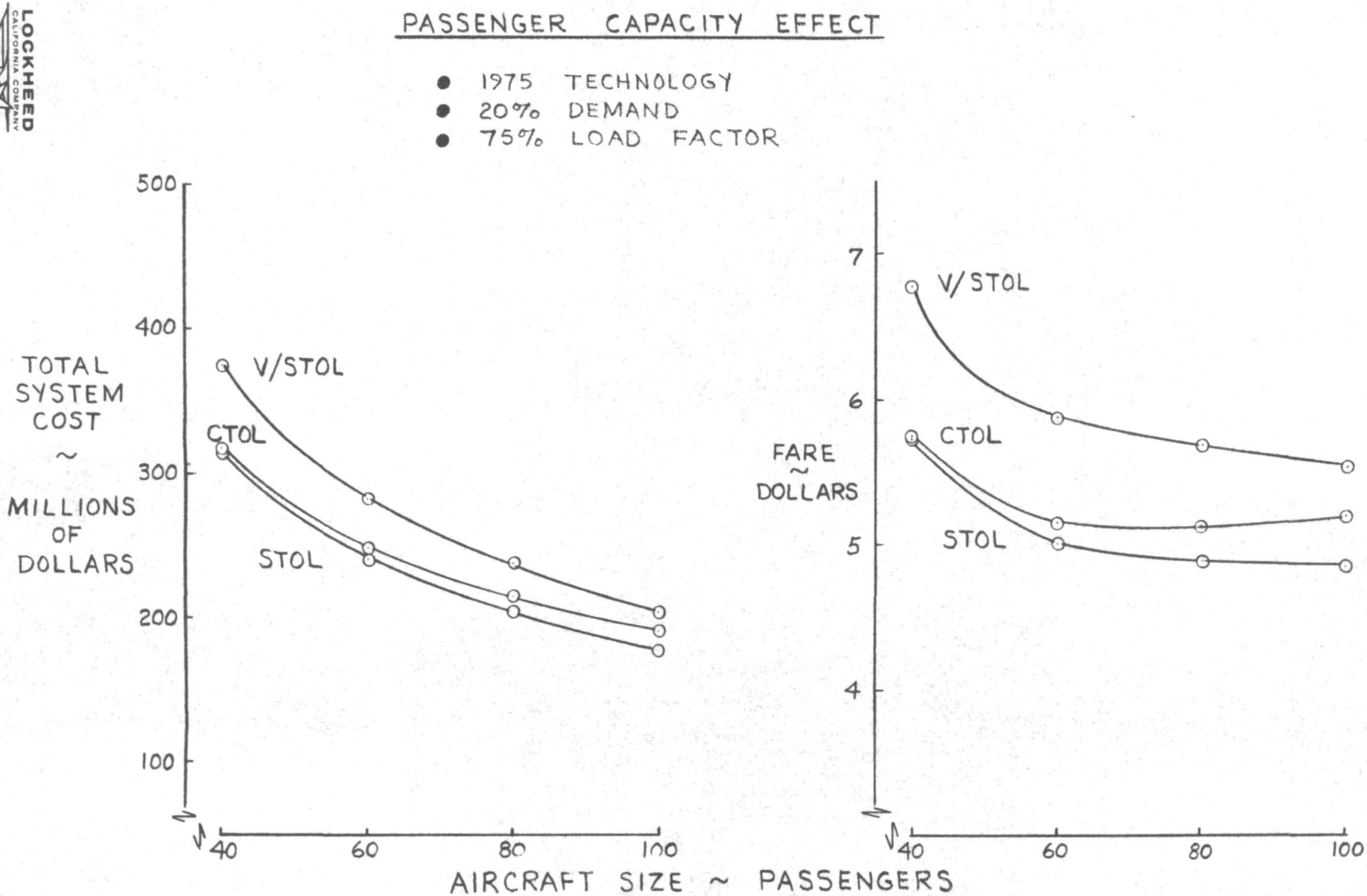

Figure 1.3-6 1975 Concept Comparison - TSC and Fare Vs. Aircraft Size

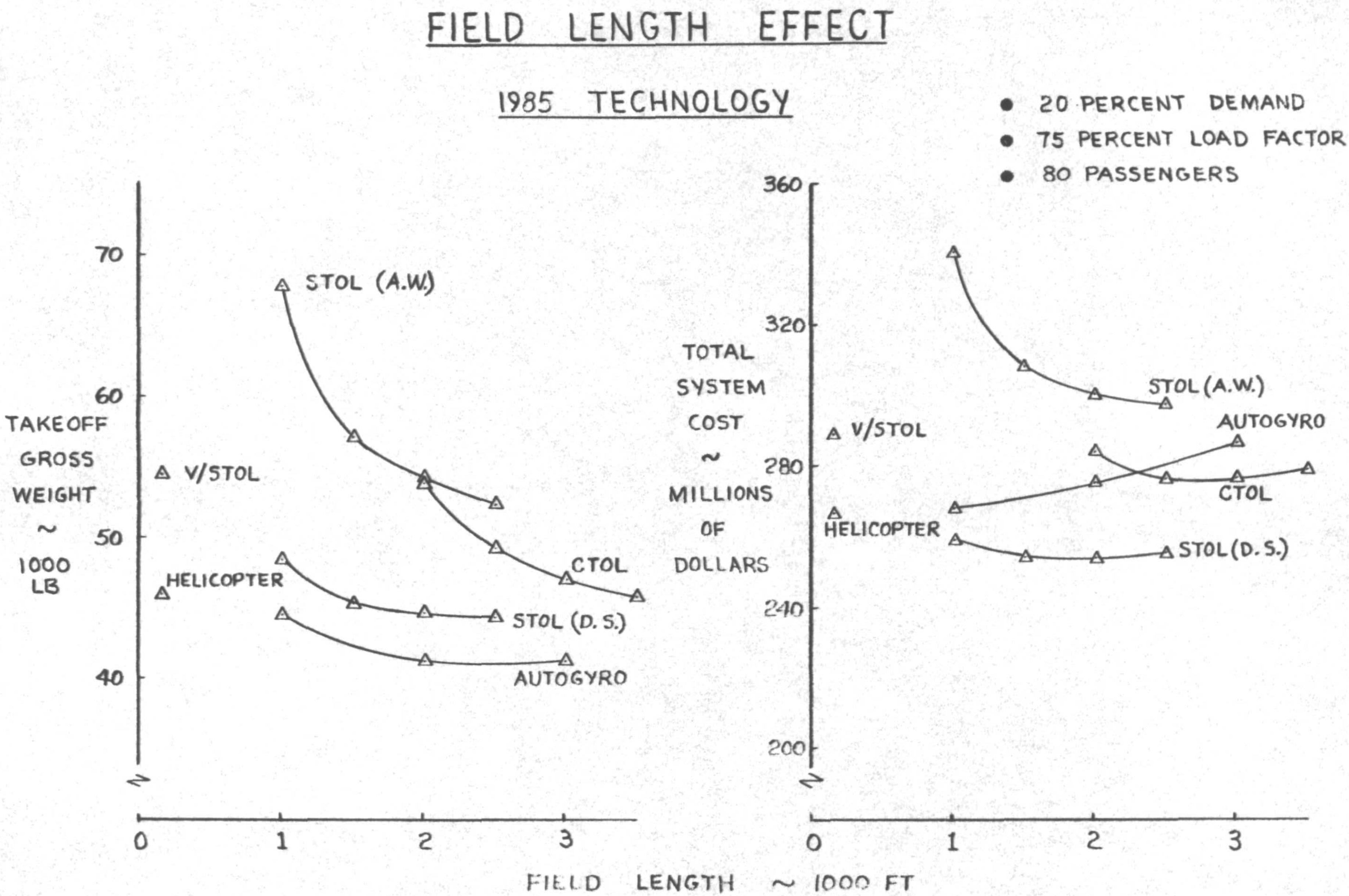

Figure 1.3-7 1985 Concept Comparison - Takeoff Gross Weight and TSC Vs. Field Length

field length of 2000 feet and the CTOL concept at 2800 feet. The augmented wing shows a steady improvement in TSC for the interval of field lengths examined (1000 to 2500 feet).

The minimum TSC for the autogyro occurs at 1000 feet. Increasing the field length beyond this point only increases the TSC. Using these near optimum field lengths for each of the concepts and the same demand conditions, the effect of aircraft size is examined on Figure 1.3-8. For all of the concepts examined, the TSC continues to decrease as aircraft size is increased due to the reduced fleet size requirements. Under these particular market demand conditions, none of the 1985 technology concepts show a optimum fare as a function of aircraft size. All of the concepts are pushed to the largest aircraft size considered to minimize the fare.

Examining the results of both the 1975 and 1985 technology time periods, it appears that under the market demand conditions used in this investigation, the deflected slipstream STOL is the minimum total system cost and fare concept. This concept is then examined in greater detail for the 1975 time period. Figure 1.3-9 is a bar diagram showing the makeup of the total system cost for variations in the field length and varying the demand from 10 to 30% holding the aircraft size constant at 100 passengers and the minimum load factor at 75%. The overriding conclusion that can be made from evaluating this bar chart is that runway length is a very insensitivity parameter to examining the Detroit area due to the low cost of land in this city.

The operating cost of this facility (terminals) and the aircraft accounts for over 75% of the total system cost. The acquisition cost of the aircraft goes down with increased runway length and the facility and equipment cost goes up with increased runway length. One just about offsets the other.

Picking a runway length of 1500 feet for the 1975 deflected slipstream STOL and holding the market demand at 20%, the effect of aircraft size and minimum load factor is shown on Figure 1.3-10. Decrease the number of passenger per aircraft increases the aircraft acquisition cost and the aircraft operating cost due to the expanded fleet size required with

PASSENGER CAPACITY EFFECT

- 1985 TECHNOLOGY
- 20% DEMAND
- 75% LOAD FACTOR

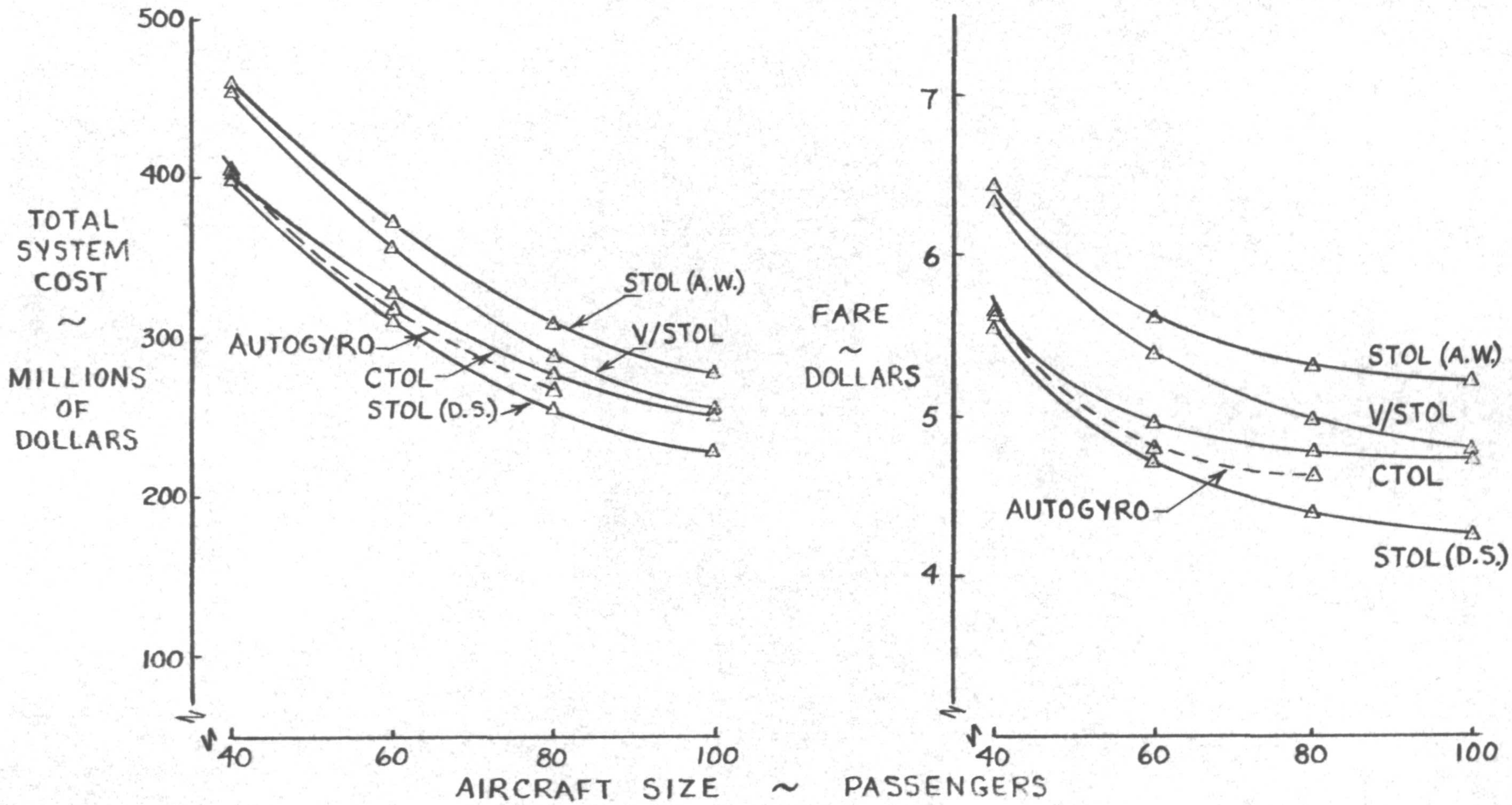

Figure 1.3-8 1985 Concept Comparison - TSC and Fare Vs. Aircraft Size

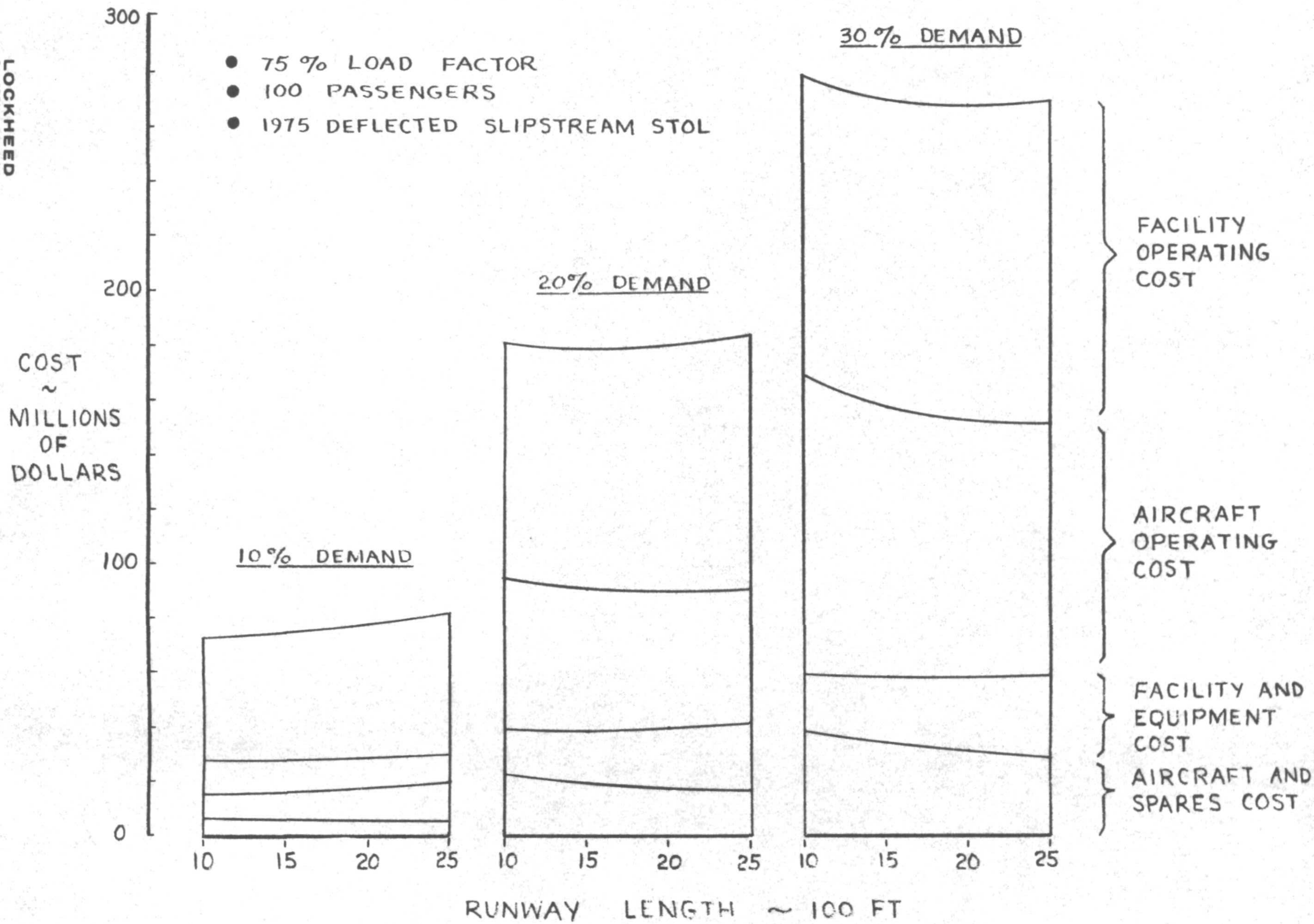

Figure 1.3-9 Total System Cost Makeup Vs. Runway Length

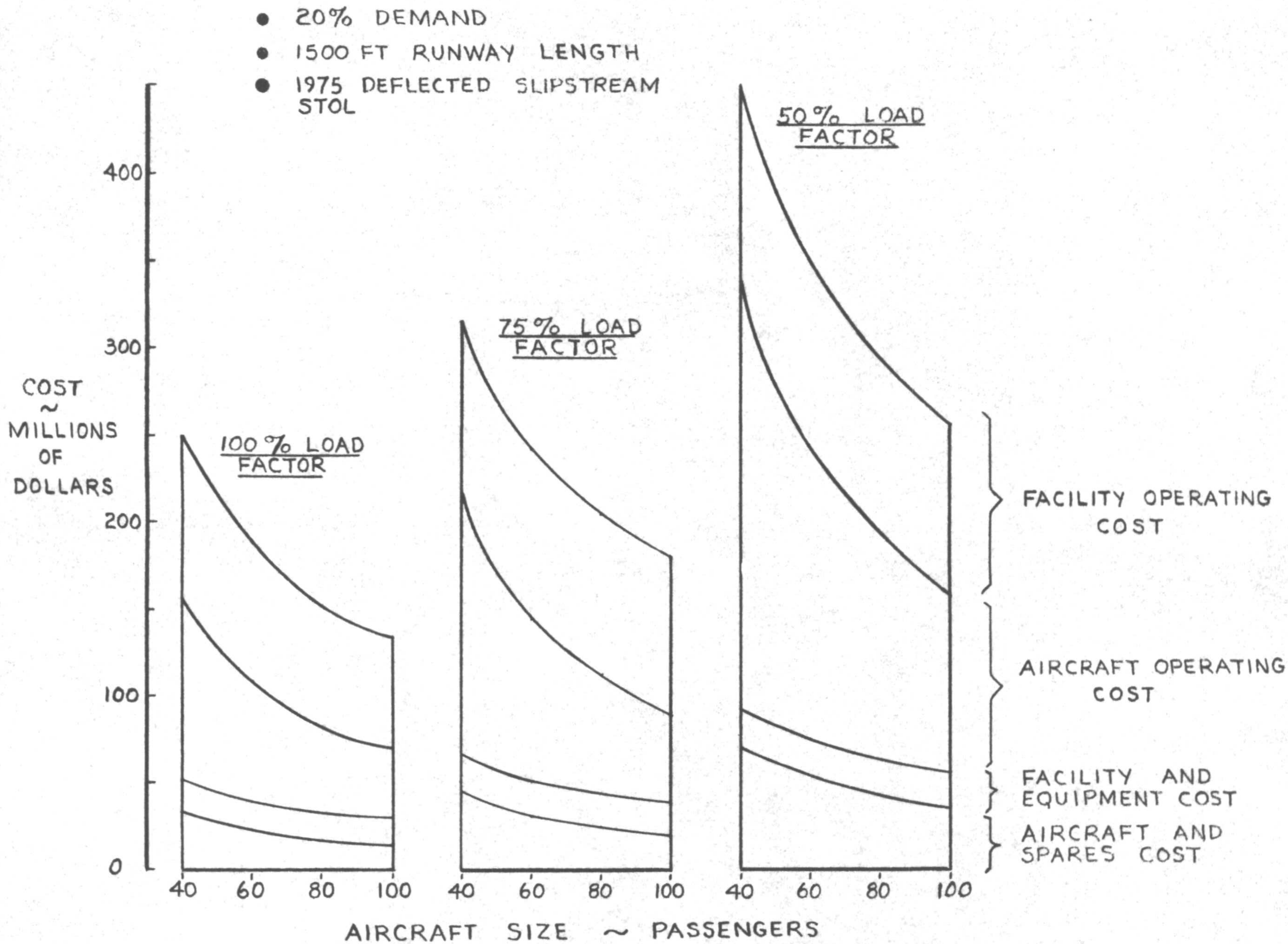

Figure 1.3-10 Total System Cost Makeup Vs. Aircraft Size

smaller airplanes. The DOC start to dominate the TSC picture when the aircraft size starts to get small. The acquisition cost and operating cost of the facilities is relatively insensitivity to these small changes in fleet size.

1.3.1.2 System Cost

The total system cost (TSC) is a combination of DOC and IOC and therefore consider the same expenses and cost. The major difference is that the total system cost shows the purchase of aircraft, equipment and facilities in total whereas in the IOC/DOC models these items are converted to an annual cost and combined with the other operating expense. Since DOC/IOC costs are tied so closely with total system cost they are also discussed in this section. Figure 1.3-11 shows the relationship between the TSC model and the other cost models. The method used to obtain the elements of DOC is shown in paragraph 1.2.1.3.3. The method for obtaining the elements of cost for total system cost and IOC is contained in the following paragraphs. The cost factors and input section (paragraph 1.3.1.2.10) gives further explanation of the model. The total system model is composed of the following elements

- RDT&E
  - Airframe
  - Engines
  - Avionics
- Investment
  - Aircraft
  - Terminals
  - Equipment
- Operations
  - Aircraft
  - System

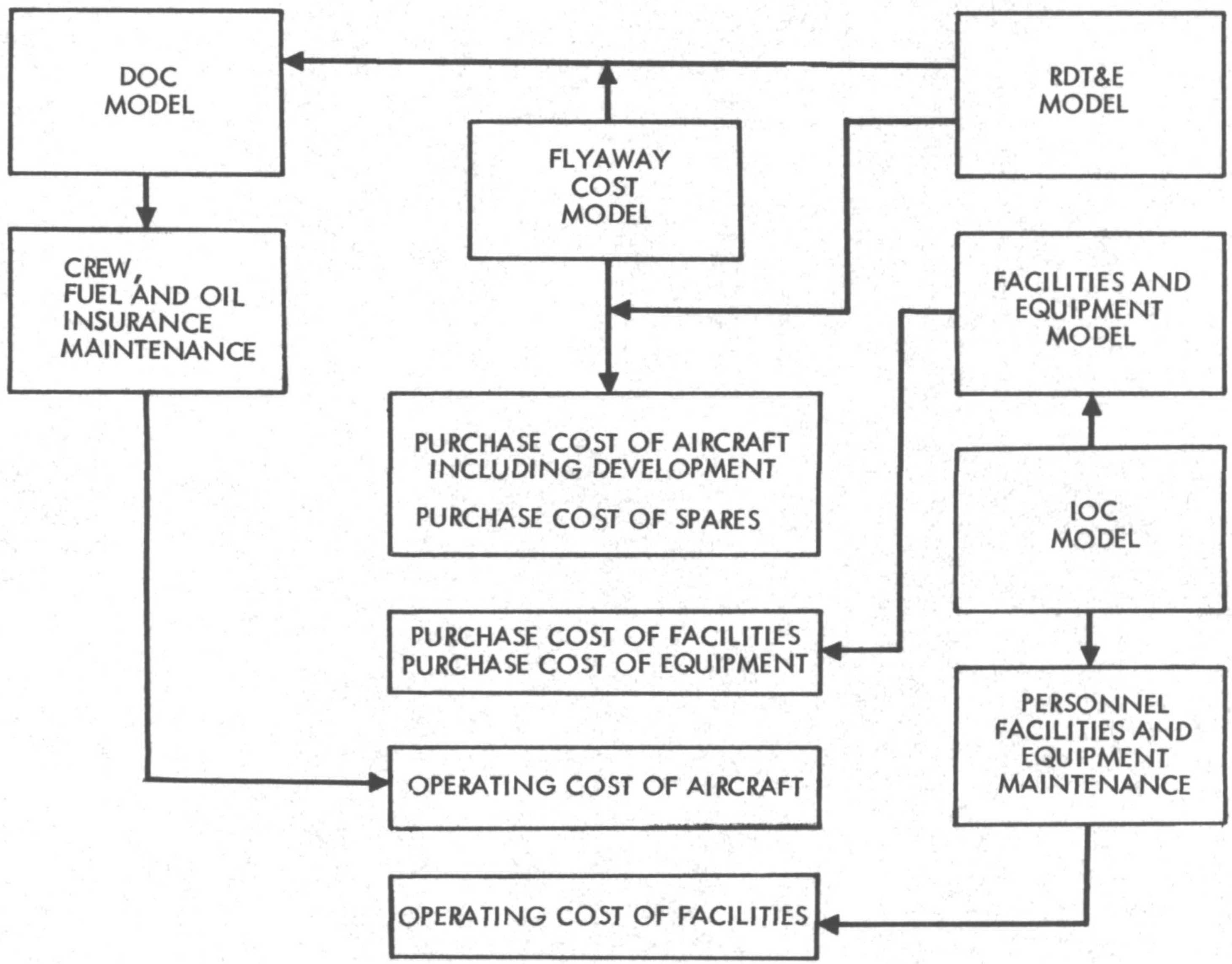

FIGURE 1.3-11. TOTAL SYSTEM COST

The total system cost is devised to account for the cost for the development of the aircraft and its components, the purchase of the aircraft and facilities and equipment, and the operating cost for the aircraft and system elements for a specified period of time. The total development cost for the aircraft is not charged to the Detroit intraurban aircraft transportation system. It is assumed that this same aircraft will be used in other cities and the development cost for the Detroit system will be in ratio to the number required for Detroit to the 300 aircraft total used in the amortization of the RDT&E.

The operating period for the facilities and equipment is the same as the depreciation period for the aircraft. The useful life span of the facilities is much longer than aircraft or equipment and only that portion of the cost used for this aircraft system is charged to total system cost. This leaves a residual value for facilities for the next aircraft system.

- Facilities Cost

The terminal complex is composed of 9 passenger terminals, a maintenance facility and a headquarters facility which is located at one of the passenger terminals. The maintenance facility is used solely for maintenance and fueling. Only emergency maintenance and fueling are accomplished at the passenger terminals. The terminal locations are discussed in section 1.1.4. The terminal costs are dependent upon the runway length, the number of gates and the number of passengers that must be accommodated during the peak period.

All of the terminals with the possible exception of New Center (NC) and Central Business District (CBD) are considered built at ground level, with the runway separate from the passenger facilities and loading and unloading gates. The major difference in the helicopter facilities is the length of the runway. The runways at NC and CBD may have to be elevated. But the extra cost for construction of the elevated runway will be offset by building it over parking space, established roadways or shoreline warehouses. The available expensive land would offset the extra construction cost.

The cost equations are written in a general manner even though each terminal is sized in accordance with the parameters mentioned above.

Number of Gates (at each terminal)

$$XNGT_i = FLTS_i \left(\frac{GT}{180}\right)$$

$$i = 1, 2, - - - - -, 10$$

each calculation for number of gates is rounded to the next highest integer

Total Number of Gates

$$TNGTS = \sum_{i=1}^{10} XNGT_i$$

- **Systems Personnel**

Traffic Servicing

$$TRAFP = TNGTS\ (PERST)$$

Ramp Personnel

$$RAMPP = TNGTS\ (PERSR) + \left(\frac{XNAC}{5}\right) PERSF$$

Dispatch and Communications

$$DSPSGP = TNGTS\ (PERSD)$$

Reservation and Sales

$$SALESP = TNGTS\ (PERSS)$$

Servicing and Administration

$$ADMINP = (TRAFP + RAMPP + DSPCHP + SALESP)\ APR$$

Total Systems Personnel

$$TOPERS = (TRAFP + RAMPP + DSPCHP + SALESP + ADMINP)\ SHFT$$

Total Annual Personnel Cost

$$PERCST + (TOPERS)\ PAY$$

- <u>Terminal Land and Terminal Facilities Cost</u>

The amount of land required for each terminal is a function of the runway length, the number of gates and the number of passengers accommodated. The amount of passenger facilities required is determined by the number of passengers during the peak hours which in turn establishes the amount of land for the passenger facility. The runway, passenger facilities, and gates are considered separately in terms of square footage requirement for construction and land. The ratios of land to facility area is noted in the input listing found in section 1.3.1.2.9.

Terminal Land

$$XLAi = 300(RUN)RLAND + XNGTi(AAC) + PASSi(AFAC)$$

Total Terminal Land

$$TRMLA = \sum_{i+1}^{N} XLAi$$

Maintenance Facility Land

$$XLAMF = 300(RUN)RLAND + \left(\frac{XNAC}{3}\right)AAC$$

Terminal Cost

$$TRMCi = GTCF(XNGTi) + FACF(PASSi) + RUNCF(RUN)\left(\frac{TOGW}{40{,}000}\right) + LACFi(XLAi)$$

Headquarters Facility Cost

$$HQTCST = HQTPR(HQTPCF)(TOPERS)$$

Total Terminal Cost

$$TRMCST = \sum_{i=1}^{N} TRMCi + HQTCST$$

Maintenance Facility Cost

$$XMNTFC = (RUNCF)RUN\left(\frac{TOGW}{40,000}\right) + XMFCF\left(\frac{XNAC}{3}\right)\frac{TOGW}{40,000}$$

$$+ LACFMF(XLAMF)$$

Total Facilities Cost

$$TFACST = TRMCST(SUBF) + XMNTFC$$

Total Terminal Land Cost

$$TRMLAC = \sum_{i=1}^{10} LACFi(XLAi)$$

- Other Expense

Advertising and Publicity

$$PUB = (APASS)(PCF)$$

General and Administration

$$G\&A = PERCST(GACF)$$

Total Other Expense

$$OEXP = PUB + GA$$

- <u>Ground Equipment</u>

$$GRDE = XNAC \left[CT(GECF) + TLAB(SMEF)\right]$$

- <u>Maintenance - Ground Property and Equipment</u>

$$XMPROP = \left[GRDE(XMCFGE) + TFACST(XMCFAF)\right] SUBOF$$

- <u>Maintenance Burden - Ground Property and Equipment</u>

$$SMBPE = XMPROP(SMBFPE)$$

The total system cost is comprised of the prorated development cost for the aircraft, the purchase cost of the aircraft and equipment and the operating cost of the aircraft and facilities. The development cost is determined in the IOC model. The development cost is prorated over a total buy of 300 aircraft. Since only a portion of the 300 aircraft are required for the Detroit intraurban system, the cost is adjusted accordingly. A subsidy factor is included in the expression for the purchase cost of the aircraft, which includes the R & D, to facilitate the examination of subsidy versus fare.

1.3.1.2.1 Purchase Cost of Aircraft

$$PAC = \left[CT - \left(\frac{RDT\&E}{XNV}\right) SUBD\right] XNAC$$

1.3.1.2.2 Puchase Cost of Aircraft Spares

$$PACSP = \left[TAPC(KSPA) + TENGC(KSPE) + AVC(KSPAV)\right] XNAC$$

1.3.1.2.3 Purchase Cost of Facilities

The total purchase cost of facilities is factored by the ratio of the depreciation period of the aircraft to the depreciation period of the facilities. The system is charged with only the facilites cost for the life span of the aircraft. The next 12 years of facilities cost would be charged to the next aircraft and so on.

An expression for landing fee cost has been included in the formula for facilities cost. This is to allow for different assumptions pertaining to Grants or Subsidy. If the system operator has to pay for the complete system including facilities then there is no landing fee. If the facilities are established by an agency or other group then the operators would probably be charged a landing fee, and would be part of his indirect cost.

$$PFAC = (TFACST)\frac{DA}{DAI} + XLDGS(XLFEE)DA$$

1.3.1.2.4 Purchase Cost of Ground Equipment

$$PEQUIP = GRDE$$

1.3.1.2.5 Operating Cost of Aircraft

The operating cost of the aircraft includes both IOC and DOC. Not all of the elements of IOC and DOC are included here because they also include the depreciation of the aircraft, equipment and facilities, and these are included as investment cost in the total system cost context. The DOC elements are shown in paragraph 1.2.1.3.3.

$$OPAC = \left[DOCFC + DOCFO + DOCI + DOMT\right] DA(XNAC)$$

1.3.1.2.6 Operating Cost of Facilites

$$OPFAC = \left[XIOCP + XIOCOE + XIOCM + XIOCMB\right] DA$$

$$XIOCP = PERCST$$

$$XIOCOE = OEXP$$

$$XIOCM = XMPROP$$

$$XIOCMB = XMBPE$$

1.3.1.2.7 Total System Cost Summary

$$TSC = PAC + PACSP + PFAC + PEQUIP + OPAC + OPFAC$$

1.3.1.2.8 Indirect Operating Cost

The elements of the indirect cost are calculated as shown by the equations in the total system cost model. The additional calculation required to convert to an IOC term is to depreciate the cost of the facilities and ground equipment. The depreciation period for the equipment is taken to be the same as the aircraft (12 years). The depreciation period for the facilities is 35 years.

- Depreciation of Terminal Facilities

$$XIOCF = \left(\frac{TRMCST - TRMLAC}{DA1}\right)(SUBF) + \frac{XMNTFC -}{DA1}$$

$$LACFMF(XLAMF) + LDGS(XLFEE)$$

- Systems Personnel

$$XIOCP = PERCST$$

- Other Expense

$$XIOCOE = OEXP$$

- Maintenance - Property and Equipment

$$XIOCM = XMPROP$$

- Maintenance Burden - Property and Equipment

$$XIOCMB = XMBPE$$

- Depreciation of Ground Equipment

$$XIOCGE = \frac{GRDE}{DA2}$$

- Total Indirect Operating Cost

The indirect operating cost is in terms of dollars per year for the total aircraft in the fleet. This is converted to dollars per year per aircraft to be comparable with the DOC.

$$XIOC = \left[XIOCF + XIOCP + XIOCE + XIOCM + XIOCMB + XIOCGE \right] / XNAC$$

- Other Calculations

Certain other calculations are required to provide information in the proper form for the evaluation process. The calculations are shown below. The symbol definitions are shown in table 1.3-1.

Average trip Distance $RANGAV = \frac{DRANGE}{DNFLTS}$

$$RANGE = RANGAV$$

Total Flight Time $TF = TCRUZE + TTOAM + TCLIMB$

$$TCRUZE = \frac{RANGE}{VCRUZ}$$

Block Time $TB = TF + TGM + GT$

Total Number of Daily Flights (including maintenance)

$$DNFLTS = DNFLTS \left[1 + \left(\frac{TB}{2}\right) \frac{XMRANG}{RANGAV} \right]$$

Total Number of Landings per Year

$$XLDGS = DNFLTS\ (365)$$

Fleet Size $XNAC = \frac{PNFLTS}{PNFLAC}$

Annual Number of Passengers $APAS = DPASS\ (365)$

Average Load Factor $LFAVRG = \frac{DPASS/DNFLTS}{XNPASS}$

Utilization (yearly) $U = TB(DNFLTS)\ 365/XNAC$

Average Number of Flights per Year

$$ANFLTS = DNFLTS\ (365)$$

TABLE 1.3-1 DEFINITION OF SYMBOLS

Symbol Definition	Symbol
The number of gates at each terminal (see sample input table for terminal designations)	XNGTi
The number of flights during the peak 3 hour period for each terminal	FLTSi
The total number of gates - all terminals	TNGTS
The number of personnel per terminal gate	PERST
The number of personnel per ramp	PERSR
The number of personnel at maintenance facility for fueling	PERSF
The number of personnel for dispatch and communications	PERSD
The number of personnel for advertising and sales	PERSS
Ratio of administrative and servicing personnel to other personnel	APR
Number of work shifts per 24 hours	SHFT
Average annual pay of personnel	PAY
Length of runway (feet)	RUN
Ratio of land to area of runway	RLAND
Ratio of land to number of gates	AAC
Ratio of land required for passenger facilities to number of passengers during peak hours	AFAC
Number of aircraft in fleet - Detroit only	XNAC
Cost per gate	GTCF
Passenger facility cost factor per passenger	FACF
Runway cost factor	RUNCF
Aircraft gross takeoff weight	TOGW

TABLE 1.3-1 DEFINITION OF SYMBOLS (Continued)

Symbol Definition	Symbol
Land cost factor for each terminal	LACFi
Ratio of headquarters people to other system personnel	HQTPR
Maintenance facility cost factor	XMFCF
Gate time - time to load or unload	GT
Headquarters facility cost factor	HQTPCF
Maintenance facility land cost factor	LACFMF
Subsidy factor for facilities	SUBF
Annual number of passengers for all facilities	APASS
Publicity cost factor per passenger	PCF
G&A cost factor per total system personnel	GACF
Flyaway cost of the aircraft	CT
Ground equipment cost factor	GECF
Maintenance equipment cost factor	XMEF
Maintenance cost factor for ground equipment	XMCFGE
Maintenance cost factor for facilities	XMCFAF
Maintenance burden factor for property and equipment	XMBFPE
Total development cost of the aircraft	RDT&E
Total number of aircraft sold	XNV
Subsidy factor for development	SUBRD
Aircraft airframe cost	TAPC
Airframe spares factor	KSPA

TABLE 1.3-1 DEFINITION OF SYMBOLS (Continued)

Symbol Definition	Symbol
Production cost for engines - per aircraft	TENGC
Engine spares factor	KSPE
Avionics cost - per aircraft	AVC
Avionics spare - factor	KSPAV
Depreciation period for aircraft	DA
Depreciation period for facilities	DA1
Total number of landings per year - all terminals	XLDGS
Landing fee - per landing	XLFEE
Depreciation period for ground equipment	DA2
Profit factor	PROF
General subsidy applied against operating expense	SUBG
Daily miles flown	DRANGE
Daily number of flights	DNFLTS
Total time for cruise	TCRUZE
Time for takeoff and air maneuver	TTOAM
Time to climb	TCLIMB
Average cruise speed	VCRUZ
Flight time	TF
Taxi out and Taxi in time	TGM
Maximum flight distance (maximum range)	XMRANG

TABLE 1.3-1 DEFINITION OF SYMBOLS (Continued)

Symbol Definition	Symbol
Average flight distance (average range)	RANGAV
Number of flights in the 3 hour peak period	PNFLTS
Number of flights the aircraft can make in the 3 hours	PNFLAC
Daily number of passengers	DPASS

Average Range Per Year

$$ARANGE = DRANGE\ (365)$$

$$Fare = \frac{(TSC)PROF - SUBG(APASS)DA}{APASS(DA)}$$

1.3.1.2.9 Cost Factors and Inputs

A sample listing of inputs are shown in tables 1.3-2 and 1.3-3. The passenger demand inputs are tabulated in paragraph 1.1.3. Many of the inputs remain constant, once established, for all concepts. Other inputs are treated parametrically to show effect on systems cost.

The rationale for the inputs dealing with passenger demand is treated in paragraph 1.3.1.4. The rationale for other input values and selection is covered in the following paragraphs.

Tables 1.3-2 and 1.3-3 are listings of input values for non-rotary wing and rotary wing aircraft. As noted earlier the rotary wing aircraft is not sized in the ASSET program and therefore is not costed by the models that are placed as subroutine to that program. The development and production costs for the rotary wing aircraft and its components are calculated outside of the DOC/IOC models and input for further calculation of DOC, IOC, and total system cost.

Table 1.3-2 lists the inputs for the non-rotary wing aircraft. There are two variable inputs that are directly input to the program: airport field length and gate fuel. The other variable inputs are calculated from the aircraft variable characteristics created by the parametric approach.

The lists of variable and non-variable inputs for the rotary wing aircraft is presented in table 1.3-3.

Even though the non-variable data remains constant for various concepts and operational requirements there are instances when some are made variable. The fixed inputs become variable for changing the premise on subsidy or when investigating the sensitivity of the total system cost or fare to changes in certain aspects of the program. These changes are made for selected aircraft rather than for the entire range of parametric data. These changes will be discussed in paragraphs 1.3.1.5 and 1.3.2.

TABLE 1.3-2 IOC AND TOTAL SYSTEM COST DATA
(FIXED WING)

Data	Location	Symbol	Units	Value
Aircraft Field Length (Runway)	77-A	RUN	FT	Variable
Gate Time	-B	GT	MIN	5
Gate Fuel	-C	GF	LBS	0
Depreciation Period for Facilities	-D	DA1	YEAR	35
Depreciation Period for Equipment	-E	DA2	YEAR	12
Number of Shifts Worked	-F	SHFT	-	3
Airport Land to Runway Ratio	78-A	RLAND	-	3
Airport Land per Gate	-B	AAC	FT^2	22,500
Airport Facility Land per Peak Passenger Loading	-C	AFAC	FT^2	260
Landing Fee	-D	XLFEE	$	0
Maint. Facil. Avrg. Range	-E	XMRANG	MI	20
	-F			
Operator's Profit Factor - %	79-A	PROF	-	1.15
Peak Period Number of Flights per A/C	-B	PNFLAC	-	0.7
	-C			
	-D			
	-E			
	-F			
Traffic Servicing Personnel per Gate	80-A	PERST	-	6
Ramp Servicing Personnel per Gate	-B	PERSR	-	3
Fueling Personnel per Gate	-C	PERSF	-	2
Dispatch & Comm. Personnel per Gate	-D	PERSD	-	2
Sales Personnel per Gate	-E	PERSS	-	1

TABLE 1.3-2 IOC AND TOTAL SYSTEM COST DATA (Continued)
(FIXED WING)

Data	Location	Symbol	Units	Value
Headquarter Personnel Ratio	81-A	HQTPR	-	0.05
Administrative Personnel Ratio	-B	APR	-	0.10
Facility Subsidy Ratio	-C	SUBF	-	1.0
Development Subsidy Ratio	-D	SUBD	-	0
General Subsidy per Passenger	-E	SUBG	$	0
Subsidy Factor for Facility Maintenance	-F	SUBOF	-	0
Cost per Gate	82-A	GTCF	$	500,000
Airport Facility Cost per Passenger	-B	FACF	$	2,800
Runway Cost Factor	-C	RUNCF	$/FT	440
Maint. Facility Land Cost Factor	-D	LACFMF	$/FT^2	1.0
Maint. Facility/Fleet Size Factor	-E	XMFCF	$	300,000
	-F			
Headquarter Personnel Cost Factor	83-A	HQTPCF	$	106,000
Annual Pay for System Personnel	-B	PAY	$/YR.	10,000
Publicity Cost Factor per Passenger	-C	PCF	$	0.50
General & Administ. Cost Factor	-D	GACF	-	0.15
	-E			
	-F			
Maintenance Equipment Factor	84-A	XMEF	-	0.10
Ground Equipment Cost Factor	-B	GECF	-	0.01
Maint. Cost Factor for Ground Equip.	-C	XMCFGE	-	0.05
Maint. Cost Factor for Airport Facilities	-D	XMCFAF	-	0.02
Maint. Burden Factor for Ground Prop. & Equip.	-E	XMBFPE	-	0.30
	-F			

TABLE 1.3-2 IOC AND TOTAL SYSTEM COST DATA (Continued)
(FIXED WING)

Data	Location	Symbol	Units	Value
Number of Passengers in 3-Hour Peak Period	*	PASSi		
Daily Number of Flights	*	DNFLTS		
Number of Flights in 3 Hour Peak Period	*	PNFLTS		
Daily Number of Passengers	*	DPASS		
Daily Total Range	*	DRANGE		
Number of Flights in 3 Hour Period for Each Station	*	FLTSi		

*Inputs for these items are listed in tables in Paragraph 1.1.3.4.2.

TABLE 1.3-3 DOC/IOC/TOTAL SYSTEM COST DATA (ROTARY WING)

NON-VARIABLE DATA

Data	Symbol	Unit	Value
Cruise Speed	VCRUZ	MPH	230
Number in Crew	XNCREW	-	2
Avionics Prod. Cost	AVC	$	350,000
Cost per Pound of Fuel	CFT	$/LB	0.015
Cost per Pound of Oil	COT	$/LB	0.926
Insurance Rate	IRA	-	0.03
Maint Labor Rate	RL	$/HR	5
Turbojet Maint Factor	TJMF	-	0
Turboprop Maint Factor	TPMF	-	1
Aircraft Field Length	RUN	FT	150
Gate Time	GT	MIN	5
Gate Fuel	GF	LBS	0
Depreciation - Aircraft	DA	YRS	12
Depreciation - Facilities	DA1	YRS	35
Depreciation - Equip	DA2	YRS	12
Number of Work Shifts	SHFT	-	3
Airport Land-Runway Ratio	RLAND	-	3
Airport Land per Gate	AAC	FT^2	22,500
Pass. Facility Land	AFAC	FT^2	260
Landing Fee	XLFEE	$	0
Maint Fac Ave Range	XMRANG	Mi	20
Operators Profit Factor	PROF	-	1.15
Max. Flights/AC - 3 Hrs	PNFLAC	-	7
Traffic Servicing Pers	PERST	-	6
Ramp Servicing Personnel	PERSR	-	3
Fueling Personnel	PERSF	-	2
Dispatch Personnel	PERSD	-	2
Sales Personnel	PERSS	-	1
Headquarters Pers Ratio	HQTPR	-	0.05
Admin Pers Ratio	APR	-	0.10
Facility Subsidy Ratio	SUBF	-	1.0
Development Subsidy Ratio	SUBD	-	0
General Subsidy Ratio	SUBG	-	0
Facility Maint Subsidy	SUBOF	-	0
Cost Per Gate	GTCF	$	500,000
Pass. Facility Cost/Pass.	FACF	$	2,800
Runway Cost Factor	RUNCF	$/FT	440
Land Cost - Maint Fac	LACFMF	$\$/FT^2$	1.0
Fac Cost/AC - Maint Fac	XMFCF	$	300,000

TABLE 1.3-3 DOC/IOC/TOTAL SYSTEM COST DATA (ROTARY WIND) (Continued)

NON-VARIABLE DATA

Data	Symbol	Unit	Value
Headquarters Cost - $/Person	HQTPCF	$/PER	106,000
Annual Pay	PAY	$/YR	10,000
Publicity Cost	PCF	$/PASS.	0.50
G&A Cost Factor	GACF	-	0.15
Maint Equip Factor	XMEF	-	0.10
Ground Equip Cost Factor	GECF	-	0.01
Maint Cost Factor - Equip	XMCFGE	-	0.05
Maint Cost Factor - Fac	XMCFAF	-	0.02
Maint Burden - Fac & Equip	XMBFPE	-	0.30
Spares Factor - Airframe	KSPA	-	0.15
Spares Factor - Avionics	KPPAV	-	0.50
Spares Factor - Engine	KSPE	-	0.50
Maint Burden Factor	MBF	-	1.3
Aircraft Prod. Quantity	XNV	-	300

TABLE 1.3-3 VARIABLE DATA - COMPOUND HELICOPTERS (Continued)

			1975			1985		
			40	60	80	40	60	80
	Symbol	Units	Passenger					
Flyaway Cost	CT	$	3,112,000	3,879,639	4,606,000	2,847,880	3,483,170	4,129,879
Airframe Prod. Cost	TAPC	$	1,808,112	2,409,639	3,011,640	1,449,880	1,931,170	2,405,379
Engine Prod. Cost/Engine	CPE2	$	100,000	115,000	127,000	117,000	135,000	153,300
Engine Prod. Cost/Aircraft	TENGC	$	300,000	345,000	381,000	351,000	405,000	459,900
Prod. Cost-Gear, Shafting	CSG	$	351,623	481,559	624,717	56,522	77,418	98,104
Takeoff Gross Weight	TOGW	LBS	39,500	54,000	68,500	26,000	36,000	46,000
Weight of Prop/Prop	WPROP	LBS	4,352	6,616	9,067	2,008	3,022	4,142
ESHP/ENGINE	ESHP	HP	2,550	3,500	4,430	3,760	5,200	6,650
Airframe Weight	AFWT	LBS	15,000	19,375	24,457	9,868	12,971	15,779
Wt of Gear, Shafting, etc.	WG	LBS	4,748	6,450	8,524	650	900	1,150
Block Fuel	FB	LBS	310	390	480	270	298	405
Prod. Cost-Rotors	CP	$	282,311	423,365	570,628	385,728	156,407	792,780
Develop. Cost/Aircraft	RDPA	$	654,000	775,000	864,000	697,000	797,000	914,000
Number of Engines	XNENG		3	3	3	3	3	3
Block Time	TB	HRS	0.20	0.20	0.20	0.20	0.20	0.20
Flight Time	TF	HRS	0.117	0.117	0.117	0.117	0.117	0.117

Note: Operational data is listed in Paragraph 1.1.3.4.2.

TABLE 1.3-3 VARIABLE DATA - AUTOGYRO (1985) (Continued)

			1000 FT RUNWAY			2000 FT RUNWAY		
	Symbol	Units	40 Passenger	60	80	40	60	80
Flyaway Cost	CT	$	2,480,339	2,980,339	3,580,070	2,407,000	2,887,000	3,475,000
Airframe Prod. Cost	TAPC	$	1,330,139	1,706,339	2,189,070	1,270,000	1,630,000	2,100,000
Engine Prod. Cost/Engine	CPE2	$	74,300	86,500	97,000	73,000	85,000	95,000
Engine Prod. Cost/Aircraft	TENGC	$	297,200	346,000	388,000	292,000	340,000	380,000
Prod. Cost-Gear, Shafting	CSG	$	42,703	57,832	76,100	41,700	56,900	75,000
Takeoff Gross Weight	TOGW	LBS	24,500	33,500	44,500	22,700	31,000	41,250
Weight of Prop/Prop	WPROP	LBS	1,735	2,480	3,666	1,700	2,440	3,600
ESHP/Engine	ESHP	HP	1,375	1,875	2,500	1,350	1,840	2,460
Airframe Weight	AFWT	LBS	9,838	12,590	15,637	9,650	12,400	15,400
Wt of Gear, Shafting, Etc.	WG	LBS	490	670	890	480	660	871
Block Fuel	FB	LBS	165	241	400	150	217	360
Prod. Cost-Rotors	CP	$	288,208	408,000	600,432	283,000	400,000	590,000
Develop. Cost/Aircraft	RDPA	$	503,000	578,000	653,000	495,000	567,000	645,000
Number of Engines	XNENG	-	4	4	4	4	4	4
Block Time	TB	HRS	0.242	0.242	0.242	0.242	0.242	0.242
Flight Time	TF	HRS	0.142	0.142	0.142	0.142	0.142	0.142

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Land costs by zone, that are used in the IOC and Total System Cost models, are listed in table 1.3-4.

The operational parameters are variable with percent demand load factor, and aircraft passenger capacity. The operational parameters are listed in tables in paragraph 1.1.3.4.3.

- Systems Personnel

The flight duration between terminals is very short and it is assumed that a cabin crew is not required. The system personnel therefore consists of the personnel at the passenger and maintenance terminals. Five types of personnel, other than flight crew and aircraft maintenance, are required at each terminal: traffic servicing, aircraft ramp personnel, dispatch and communication, publicity and sales, and personnel for fueling. The traffic and servicing personnel handle all baggage and cargo and process passengers at each gate. The ramp personnel are required to guide the aircraft to gate position, connect electrical lines, open passenger doors, and help with luggage. The dispatch and communication personnel keep track of flights, relay information about weather, and maintain scheduling of aircraft to and from the maintenance facility. Publicity personnel help with ticketing, posting schedules, and local publicity. The personnel for fueling are located at the maintenance facility. Only emergency fueling is accomplished at the passenger terminal and is handled by the ramp personnel.

The number of personnel assigned to each of the personnel categories is a function of the number of gates at each terminal and the fleet size. The number of personnel at the passenger terminals is a function of the number of gates which in turn is a function of the maximum number of flights during the 3 hour peak period. The number of personnel required for fueling at the maintenance terminal is a function of the fleet size. The number of personnel assigned for each category is indicated in the input listing. (reference 1.3-1)

The annual pay is an average for all personnel categories. The average annual is $10,000 per person. (reference 1.3-1)

TABLE 1.3-4 INTRAURBAN TERMINAL LAND COST
(DETROIT)

Zone	Symbol	Dollars/Acre	Dollars/Sq. Ft.
Central Business District	CBD	110,254	2.53
New Center	NC	110,254	2.53
Monroe	MON	37,941	0.87
Pontiac	PONT	73,476	1.69
Ann Arbor	ANN	62,412	1.43
Metropolitan Airport	METRO	1,359	0.03
Port Huron	PH	55,846	1.28
Algonac	AL	23,392	0.54
Mount Clemens	MCLE	61,118	1.40

There are three work shifts per 24 hour period. Two of the shifts would handle the peak load, the morning peak, and the afternoon peak. The other shift takes care of the off peak traffic and prepares the system for next day's operation. The personnel in each shift are periodically rotated to another shift to average the work load for each person.

In addition to the personnel at the passenger and maintenance terminals there are headquarters personnel that take care of policy and management administration. The headquarters personnel are located at one of the passenger terminals.

- Terminal Facilities

The cost of a terminal is comprised of the cost for the gates, runway, passenger and system personnel facilities, and land.

- Gates

The loading and unloading gates consist of the passageway inside the terminal and the mechanical covered passageway that connect to the aircraft. The gate concept is that they will be flush with the runway when not in use and raised to each side of the aircraft when loading and unloading passengers. The design of the passageways for the gates will prevent the loading passengers from interfering with the unloading passengers, and protect the passenger from weather and engine blast. The number of gates is determined by the number of flights during the 3 hour peak period. The cost of each gate is estimated at $500,000 each.

- Passenger Facilities

The amount of terminal area required per passenger for the intra-urban transportation system is small compared to the present day aircraft system terminals. The persons using the intraurban system spend very little time in the terminal and do not require eating, or comfort facilities or have time to spend browsing in shops during plane changes.

There is the possibility for the terminal operator recouping the cost of the terminal by building shopping centers within each terminal. The

easy access to shopping centers and the rapid transportation system available at each shopping location would help create off peak hour shoppers and bring in additional revenue. Another source of revenue would be to build office space at each terminal for lease. Chain store operators or other business of this nature would find the terminals extremely advantageous because of easy access to each location.

The passenger facilities are costed in the following manner. (reference 1.3-2)

10 sq ft per passenger at \$30 per sq ft	= \$ 300/pass
250 sq ft per passenger for parking at \$10 per sq ft	= \$2500/pass
TOTAL	= \$2800/pass

The number of square feet of space required for passenger facility and parking is determined by the number of passengers during the 3 hour peak period.

- Runway

The cost of the runway is based on a concrete runway at ground level and 150 feet wide. The cost per linear foot is derived by application of a cost per square foot to the area determined by the 150 foot width and 1 foot in length.

150 ft width x 1 foot length = 150 sq ft

150 sq feet x \$1.33/sq ft = \$200 per foot

Allowance for the taxi way is the same as for the runway which brings the cost for the runway and taxi strip to \$400 per foot.

Forty dollars per foot is added to the cost per foot for the runway to account for the runway and taxiway lighting. This also includes the approach lighting.

The length of runway required for the V/STOL aircraft is based on the requirements set forth in reference 1.3-3. The total area allocated to V/STOL operation is 40,680 square feet including the peripheral area. The

actual landing area is 300 feet by 150 feet. This does not include the 22,500 square feet allocated to each loading /or unloading gate. The same cost factors that are applied to the fixed wing aircraft runways are applied to the takeoff area for the V/STOL aircraft.

- Headquarters Facility

The amount of office space alloted for headquarters facility is 150 square feet per man.

$150/sq ft x $40/person = $6000 per person

The number of headquarters people is determined by assuming a ratio of headquarters people to system personnel of 20:1.

Included in the headquarters facility is the computer equipment for automatic ticketing and billing. The equipment cost is related to number of headquarters personnel which is in turn related to the size of the system.

Equipment cost = $100,000/person

The total cost for facilities and equipment is $106,000 per headquarters person, or $5300 per system personnel.

- Maintenance Facility

The cost of the runway for the maintenance facility is determined in the same manner as the passenger terminals. The cost of the maintenance buildings is determined by allocating square footage of building space for maintenance in accordance with the number of aircraft at the facility at one time. It is assumed that the maintenance facility will accommodate 1/3 of the fleet at one time. Ten thousand (10,000) square feet is allocated for each aircraft, and its associated maintenance equipment. The cost per aircraft for maintenance facility is:

10,000 sq ft/aircraft x $30/sq ft = $300,000/aircraft.

- Land

The amount of land required for each terminal is determined by the size of the runway, the square footage required for facilities

(passenger and maintenance) and the number of gates at each terminal. The method for determining the square footage for the runway and facilities is described in the above paragraphs. The square footage required for each gate, other than that within the terminal is estimated on the basis of a nominal aircraft size. The following criteria is used for determination of the land area required (see paragraph 1.3.1.2.3 for equation).

RLAND = ratio of land to runway area - allowed 3 times runway and taxi strip area

AAC = area of land for gates - allowed 150 feet x 150 feet (22,500 sq ft) for each gate

AFAC = ratio of land to square footage required for passenger facilities and parking - one to one ratio or 260 square feet per passenger at peak 3 hour period.

The land values used in the evaluation are shown in the sample input sheets.

- Ground Equipment

Ground equipment consists of the fueling and servicing equipment and maintenance equipment. The servicing equipment will be minimal because there is no food service and no air-conditioning on the aircraft. The cost of the fueling and towing equipment is a percent of the flyaway cost of the airplane. The cost of the maintenance equipment is a function of the maintenance labor cost.

1.3.1.2.10 Sample Cost Results

The costs presented in this paragraph represent only the cost for a selected aircraft for each concept. A cost breakdown of this nature is not presented for each evaluation because of the large number that were investigated. A tabular summary of DOC/IOC and TSC and other information for all aircraft evaluated for the 20% demand and 75 minimum load factor is

presented in the Appendix. The detailed costs presented here are for an 80 passenger airplane, for all concepts, 20% demand and 75% minimum load factor.

Table 1.3-5 indicates the DOC and IOC breakdown. Table 1.3-6 indicates the breakdown of total system cost, and shows total flyaway cost including development and fare and gross weight. The purpose of these tables is to show the relationship between cost and aircraft concept and runway length. Since the demand is constant for this comparison the number of aircraft in the fleet is constant for all concepts and the costs may be compared. The comparison shows that the deflected slipstream airplane has the lowest DOC ($5.00) but the compound helicopter has the lowest IOC ($5.55). This is because the deflected slipstream has lower flyaway cost, therefore less depreciation cost, and lower maintenance cost than the helicopter. The flyaway cost for the deflected slipstream is lowered using the maximum runway length (2500 feet) because the lower performance requirements and therefore a lighter airplane.

The IOC is lowest for the compound helicopter because of the difference in facility cost due to a difference in the runway lengths. The personnel cost is the same for all concepts because the number of flights and the number of passengers per day are constant for this comparison. The maintenance cost is the overriding cost for the V/STOL aircraft due to the gear boxes, shafting, and rotors, but is partially offset by the facilities cost and remains competitive with the tilt wing and the CTOL with a 3500 feet runway.

Table 1.3-7 is included to indicate the differences in cost due to the differences in demand and aircraft cost for the two time periods (1975 and 1985). The purchase cost of the aircraft and its spares increases because of the use of composite material in its construction. The cost for facilities also increases because of the increased demand.

The overall result is a decrease in fare. This is due to more passengers served for a less increase in cost. A 25% increase in total system cost but a 39% increase in number of passengers served. The facilities cost do not increase at the same rate as the increase in passengers because one passenger gate can accommodate from 80 to approximately 2000 passengers for the same cost.

TABLE 1.3-5 DOC/IOC SUMMARY - 1975

($ - 1000 EXCEPT AS NOTED)

80 PASSENGER AIRCRAFT 20% DEMAND 75% MINIMUM LF	CTOL 1975		DEFLECTED SLIPSTREAM 1975		TILT WING V/STOL	COMPOUND HELICOPTER V/STOL
	2000 ft RUNWAY	3500 ft RUNWAY	1000 ft RUNWAY	2500 FT RUNWAY	1975	1975
DOC						
FLIGHT CREW	50.9	49.8	50.1	53.1	50.1	65.7
FUEL AND OIL	69.2	47.9	79.3	56.5	110.8	67.1
INSURANCE	96.5	82.1	100.8	74.3	157.3	138.2
DEPRECIATION	328.7	282.1	344.9	254.4	533.3	462.7
MAINTENANCE	681.5	608.1	697.0	612.4	910.6	811.3
TOTAL ($/YR/AC)	1226.8	1070.0	1272.1	1050.7	1762.1	1545.0
* TOTAL ($/MI/AC)	5.84	5.10	6.06	5.00	8.39	7.36
IOC						
FACILITIES DEPR	164.7	188.3	136.7	164.0	115.7	110.4
PERSONNEL	544.0	544.0	544.0	544.0	544.0	544.0
OTHER EXPENSE	379.0	379.1	379.1	379.0	379.1	379.1
FACILITIES MAINT	198.5	268.1	143.4	215.0	99.5	95.0
MAINT BURDEN	59.5	80.4	43.0	64.6	29.9	28.5
GRD EQUIP DEFR	6.4	5.6	6.5	5.5	8.5	7.1
TOTAL ($/YR/AC	1352.1	1465.5	1252.7	1372.1	1176.7	1164.1
* TOTAL ($/MI/AC)	6.44	6.98	5.97	6.54	5.61	5.55

*COST IN DOLLARS

TABLE 1.3-6 TOTAL SYSTEM COST SUMMARY - 1975

($ - MILLIONS EXCEPT AS NOTED)

80 PASSENGER AIRCRAFT 20% DEMAND 75% MINIMUM LF	CTOL 1975		DEFLECTED SLIPSTREAM 1975		TILT WING V/STOL	COMPOUND HELICOPTER V/STOL
	2000 FT RUNWAY	3500 FT RUNWAY	1000 FT RUNWAY	2500 FT RUNWAY	1975	1975
TOTAL SYSTEM COST						
AIRCRAFT	21.6	18.4	22.6	16.6	35.2	30.9
SPARES	4.3	3.8	4.5	3.4	6.5	5.5
FACILITIES	22.4	30.5	16.1	24.4	10.9	10.4
EQUIPMENT	0.5	0.5	0.5	0.4	0.7	0.6
AIRCRAFT OPERATING	72.4	63.5	74.7	64.2	99.0	87.2
FAC OPERATING COST	95.2	102.5	89.4	96.9	84.8	84.3
TOTAL	216.4	219.2	207.8	205.9	237.1	218.9
FLYAWAY COST	3.216	2.737	3.358	2.477	5.245	4.606
*FARE ($/PASS)	5.19	5.25	4.98	4.94	5.69	5.25
GROSS WEIGHT	58,600	48,398	57,794	47,024	71,526	68,000

*COST IN DOLLARS

TABLE 1.3-7 TOTAL SYSTEM COST COMPARISON

DEFLECTED SLIPSTREAM

TOTAL SYSTEM COST ($-M)	1975	1985	% CHANGE
PURCHASE OF AIRCRAFT	22.6	35.5	+ 57
SPARES	4.5	6.9	+ 53
FACILITIES	16.1	18.3	+ 14
EQUIPMENT	0.5	0.7	+ 40
OPERATING COST OF AIRCRAFT	74.7	95.7	+ 28
OPERATING COST OF FACILITIES	89.4	101.4	+ 14
TOTAL	207.8	258.5	+ 25
AIRCRAFT FLYAWAY COST	3.358	3.878	+ 15
FARE	4.98	4.46	- 11
AVERAGE TRIP RANGE	25.08	19.53	- 28
ANNUAL MILES	1,409,630	1,497,230	+ 6.5
ANNUAL PASSENGERS	3,994,560	5,553,840	+ 39
ANNUAL FLIGHTS	61,726	85,586	+ 39
NO. OF AIRCRAFT IN FLEET	6.71	9.14	+ 36
UTILIZATION	2262	2131	- 6

$$\text{FARE} = \frac{\text{TSC (PROFIT)}}{\text{A PASS} \times 12}$$

The average trip range decreases in 1985 because more terminal pairs with shorter ranges are added as passengers served is increased. Table 1.3-8 is a breakdown, in dollars per passenger, of the items that are included in determining fare. The operating cost of the facilities and aircraft are the dominate costs. This is also shown by examination of the breakdown of the DOC/IOC and TSC. Figures 1.3-12 through 1.3-15 shows the breakdown of DOC/IOC and TSC by percent and TSC by dollars. The breakdown is consistent for all concepts. The maintenance cost is a dominate cost in DOC and personnel is a dominate cost in IOC. Since maintenance cost becomes part of aircraft operating cost in total system cost and personnel cost becomes part of facilities operating cost it then follows that these costs override all other cost in total system cost. In total system cost the operating cost are for a 12 year period; the same time period as the depreciation period for the aircraft.

This section of the report has dealt with the methodology for determining IOC and TSC and sample results for DOC/IOC and TSC. The costs results for all evaluations have been used in the Parametric Data Development (Section 1.2) and in accompanying paragraph to this section (Synthesis and Optimization).

TABLE 1.3-8. BREAKDOWN OF FARE

DEFLECTED SLIPSTREAM - 1975
($/PASSENGER)

PURCHASE OF AIRCRAFT	0.54
PURCHASE OF SPARES	0.10
PURCHASE OF FACILITIES	0.38
PURCHASE OF EQUIPMENT	0.01
OPERATING COST OF AIRCRAFT	1.80
OPERATING COST OF FACILITIES	2.15
TOTAL	4.98

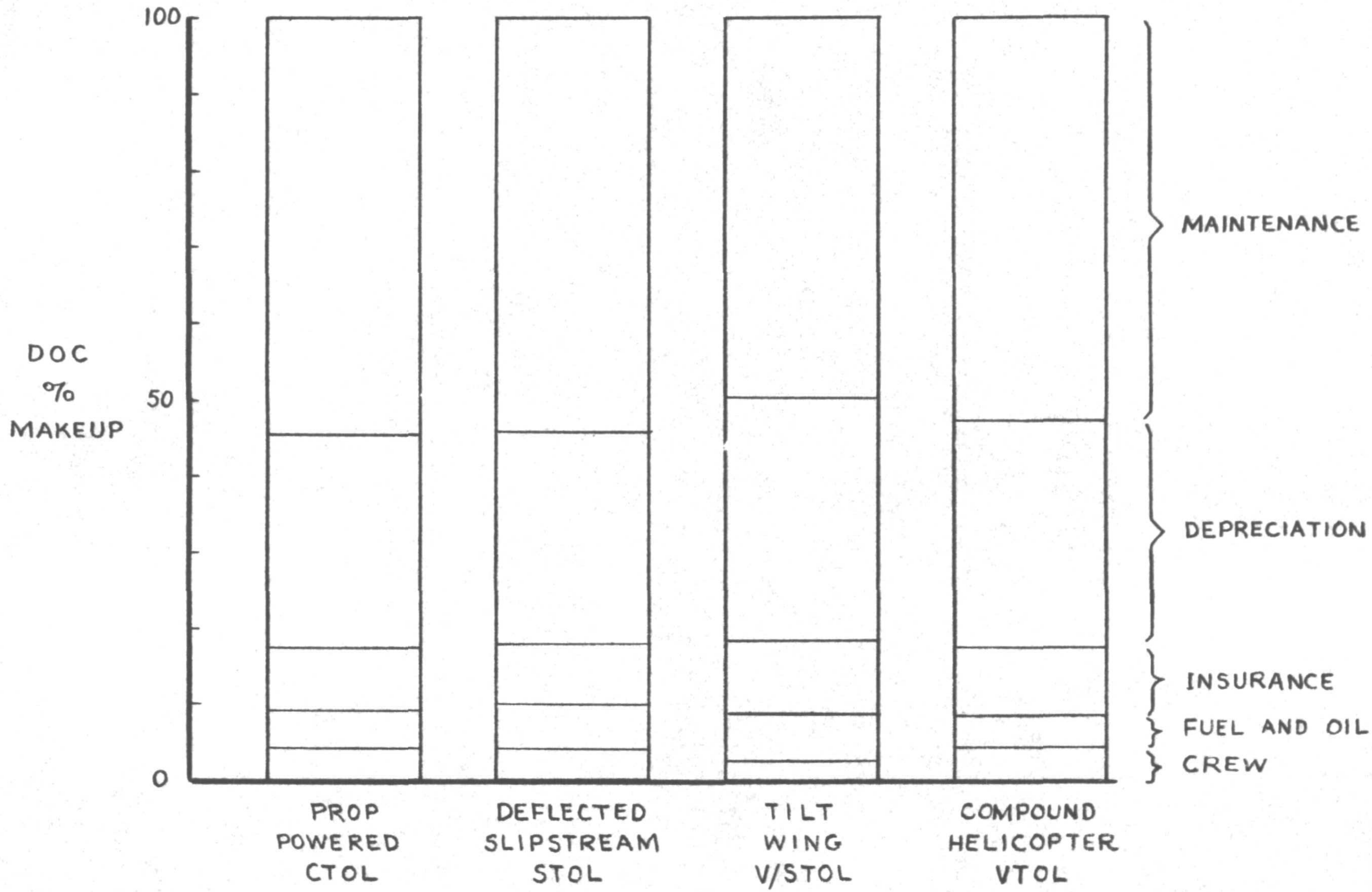

FIGURE 1.3-12. PERCENT MAKEUP OF DOC

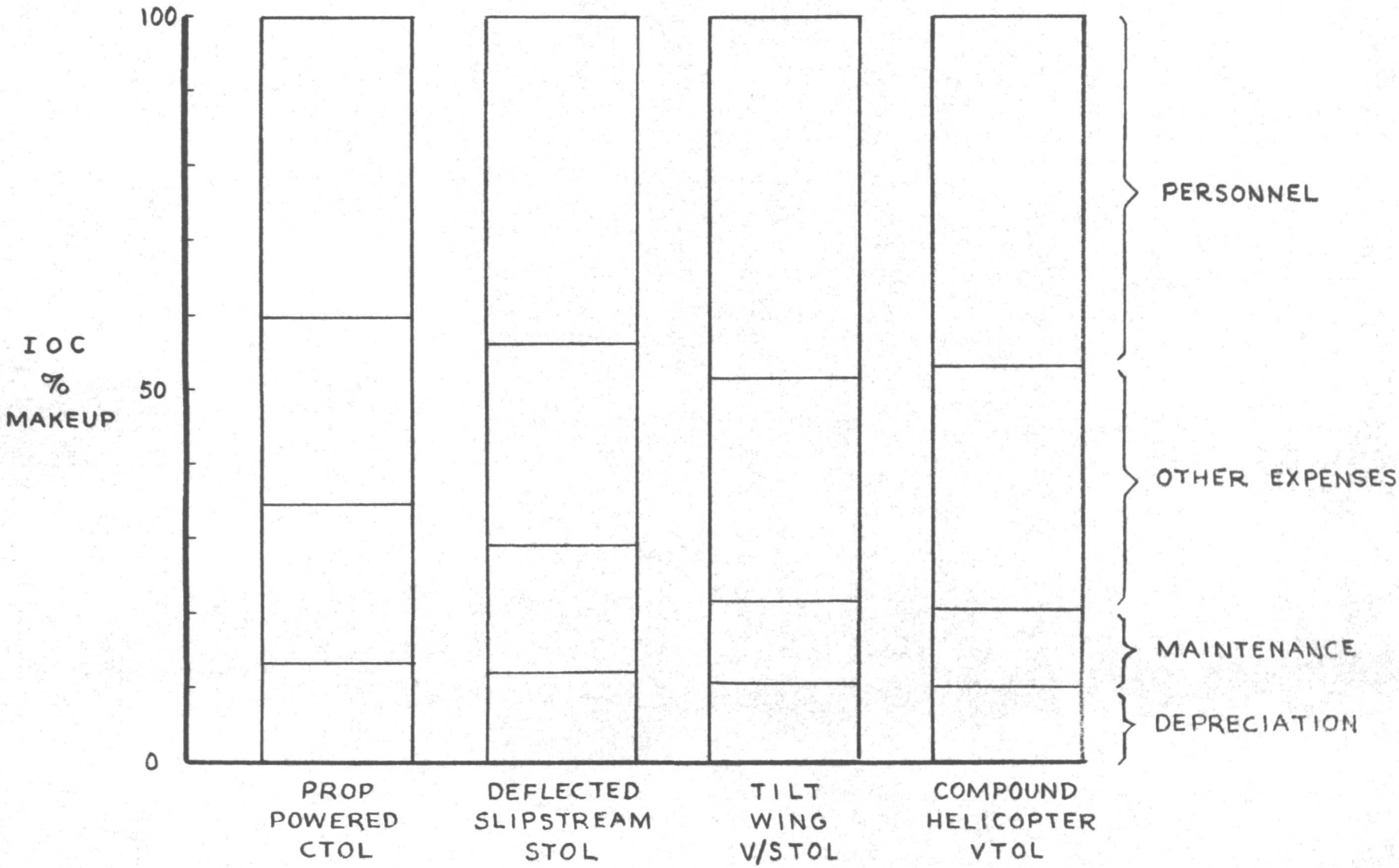

FIGURE 1.3-13. PERCENT MAKEUP OF IOC

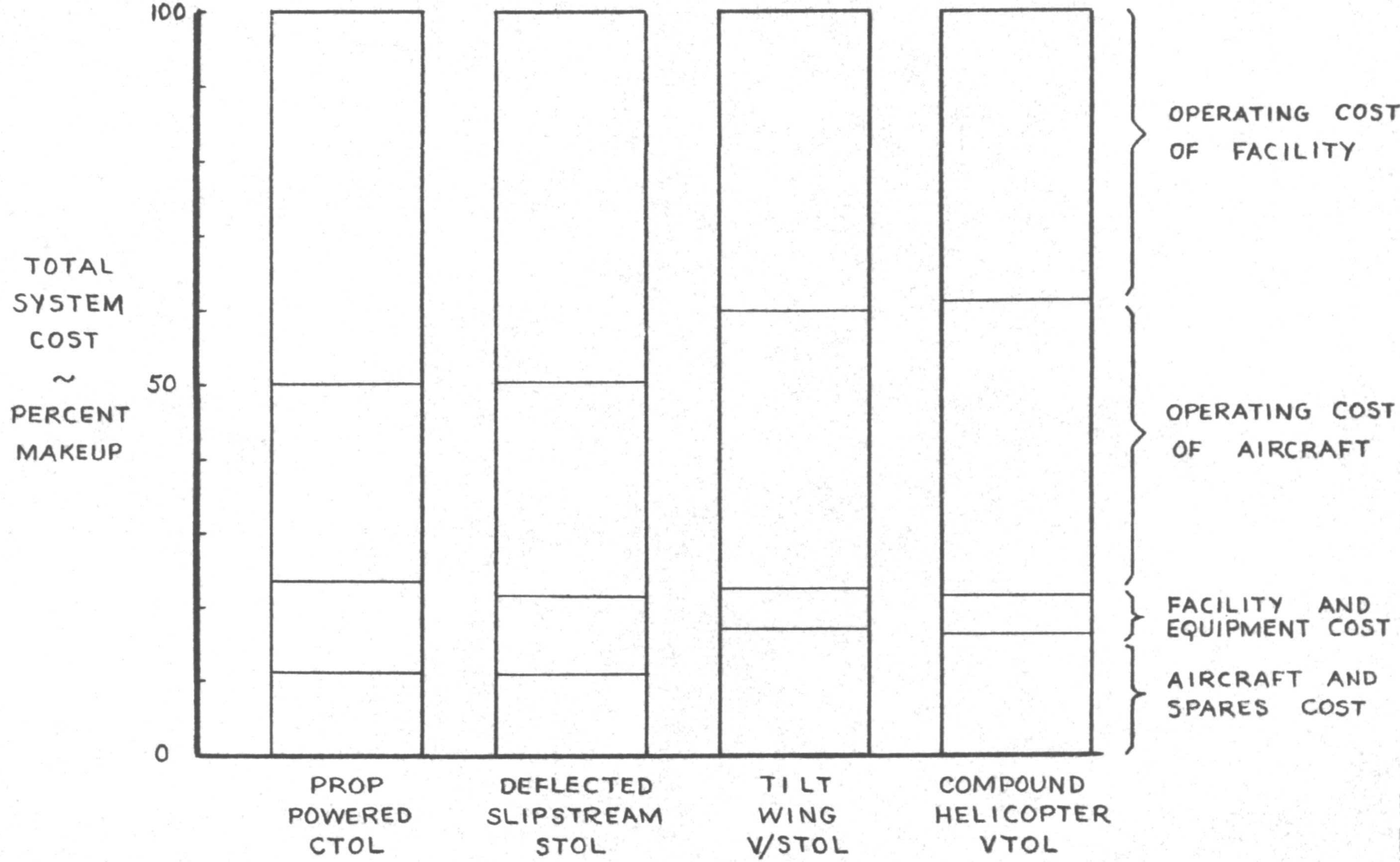

FIGURE 1.3-14. PERCENT MAKEUP OF TOTAL SYSTEM COST

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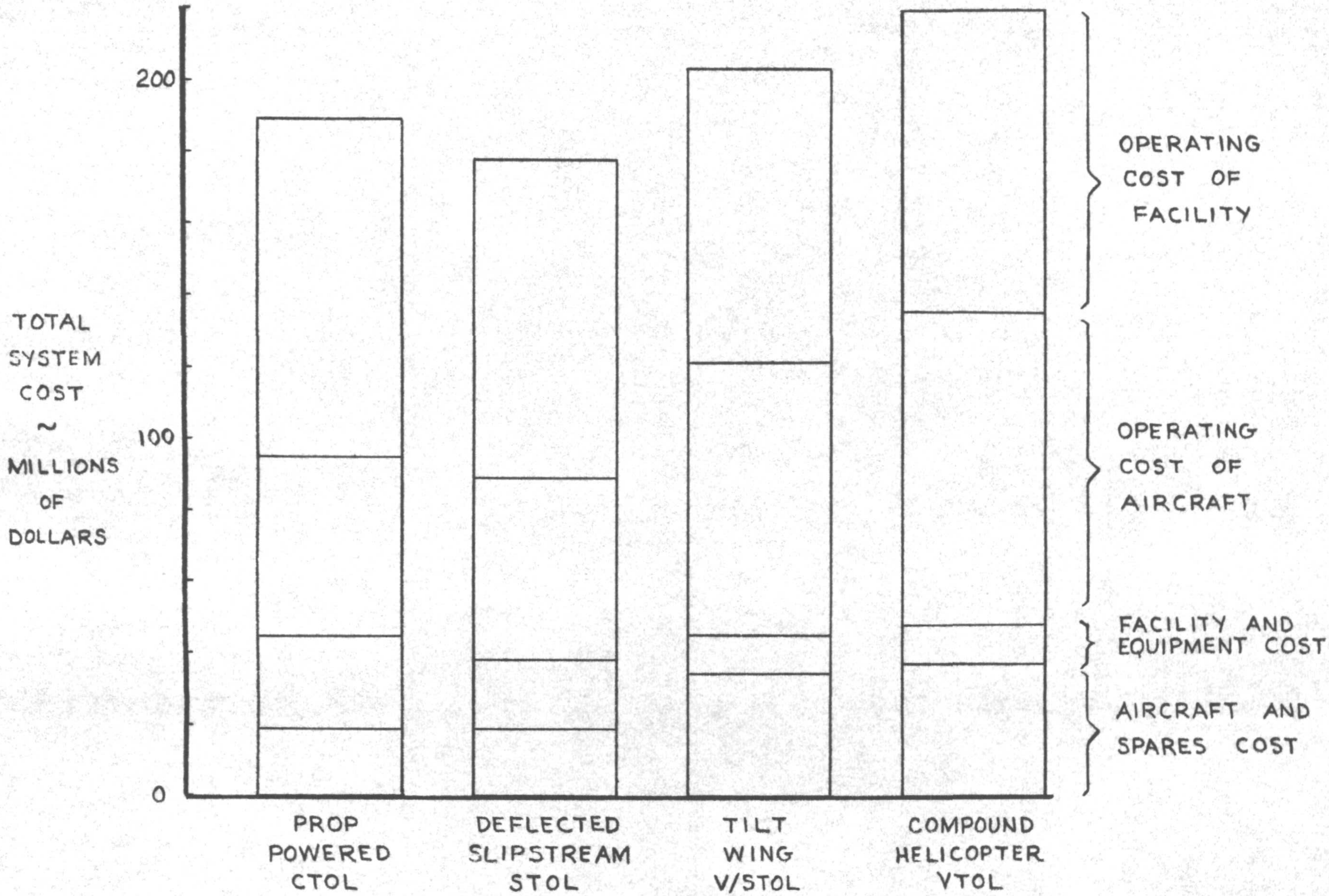

FIGURE 1.3-15. TOTAL SYSTEM COST COMPARISON

1.3.1.3 Matrix of Investigation

A broad matrix of candidate approach concepts are examined with the accent on determination of qualifying or disqualifying concept. The problem consists of matching the aircraft characteristics (aircraft size, runway length) with the market demand data (demand percentage, minimum load factor). This has to be done for each of the approach concepts and in both the 1975 and 1985 time periods. Table 1.3-9 is an example of the make up of the matrix for one concept and one time period. The overriding problem is how to analyze this mass of data in a logical and meaningful way which results in a relative stacking of the different approach concepts.

TABLE 1.3-9. MATRIX OF INVESTIGATION

DEMAND	AIRCRAFT PASSENGER CAPACITY / RUNWAY LENGTH / MINIMUM LOAD FACTOR	40				60				80				100			
		1000	1500	2000	2500	1000	1500	2000	2500	1000	1500	2000	2500	1000	1500	2000	2500
10%	50%	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	75	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	100	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
20%	50%	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	75	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	100	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
30%	50%	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	75	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	100	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

1.3.1.4 Total System Synthesis Methodology

In order to be able to select the relative best aircraft of the VTOL concepts and the best aircraft of the STOL concepts it is necessary to develop some consistent method of evaluating all of these approach concepts in a logical matter which includes all of the parameter variations.

A technique has been developed wherein it is possible to do this comparison analysis. This technique has the inherent capability of allowing for many methods of analysis using the same basic curves required for any one of the methods. Lockheed has chosen to do this relative comparison analysis by two of these methods as a cross check. The two methods chosen to be used are:

- Minimum fare method
- 20 minute schedule at the highest demand terminal pair.

Examples of some of the other possible methods of analysis are:

- Fixed aircraft size (no. of passengers)
- Fixed fleet size
- Any particular fixed fare
- Any particular fixed schedule.

One point of warning, when using these methods, you can not make initial assumptions and solve for predicted demand. This data is not based on a mode split method and all of the demand data is handled parametrical, but still being based on real Detroit demand data. The data herein will not predict the expected demand for a given fare or waiting period. This data is only the results of varying the basic demand data.

Figures 1.3-16 through 1.3-19 are illustrative examples of the minimum fare method of analysis. The data presented in these figures are the results from the total system synthesis program where all of the major aircraft and marketing variables were varied parametrically to form the matrix of investigation. This data is then plotted for each approach

- TRUE FOR ONLY ONE MINIMUM LOAD FACTOR

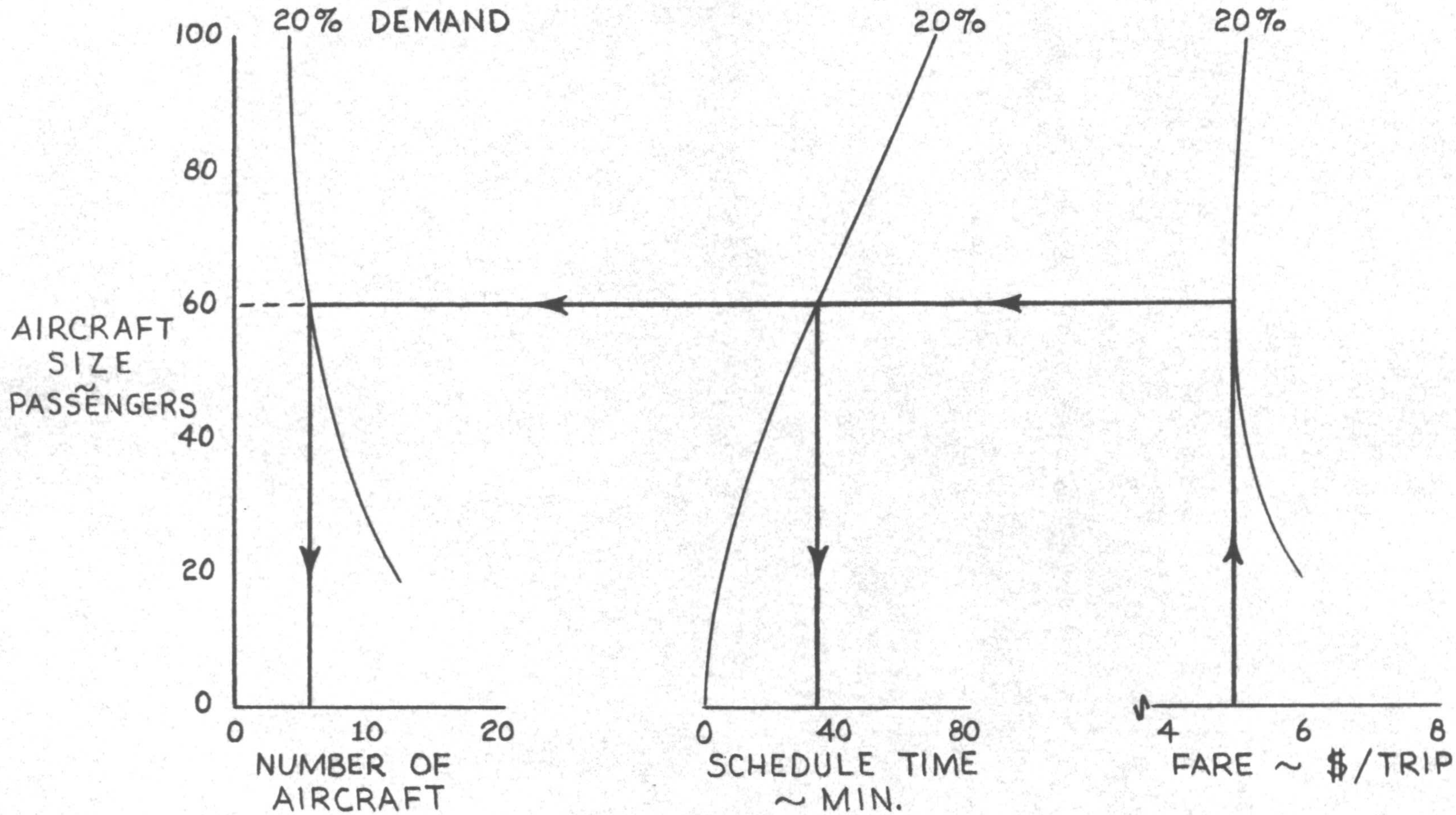

FIGURE 1.3-16. MINIMUM FARE METHOD - STEP 1

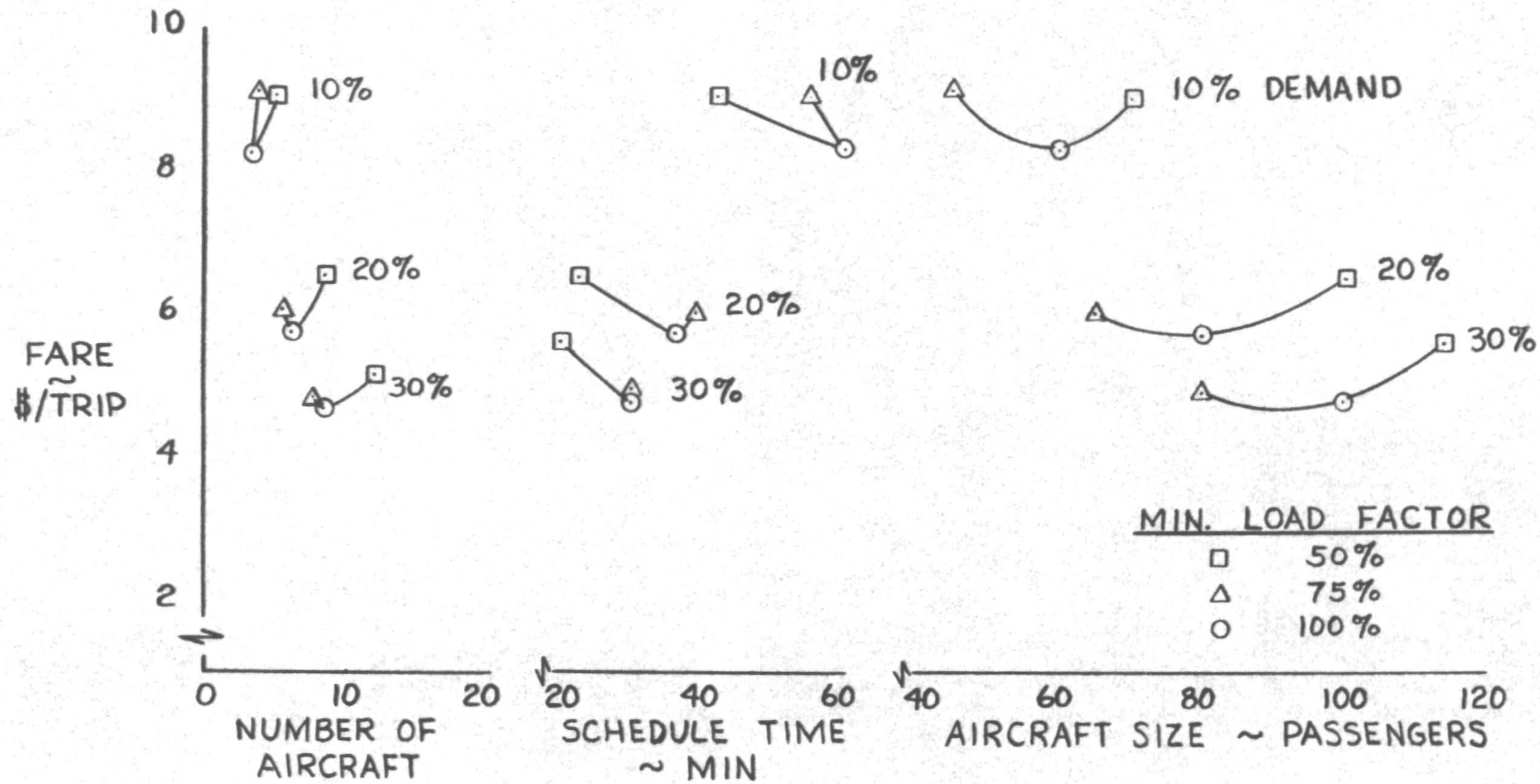

FIGURE 1.3-17. MINIMUM FARE METHOD - STEP 2

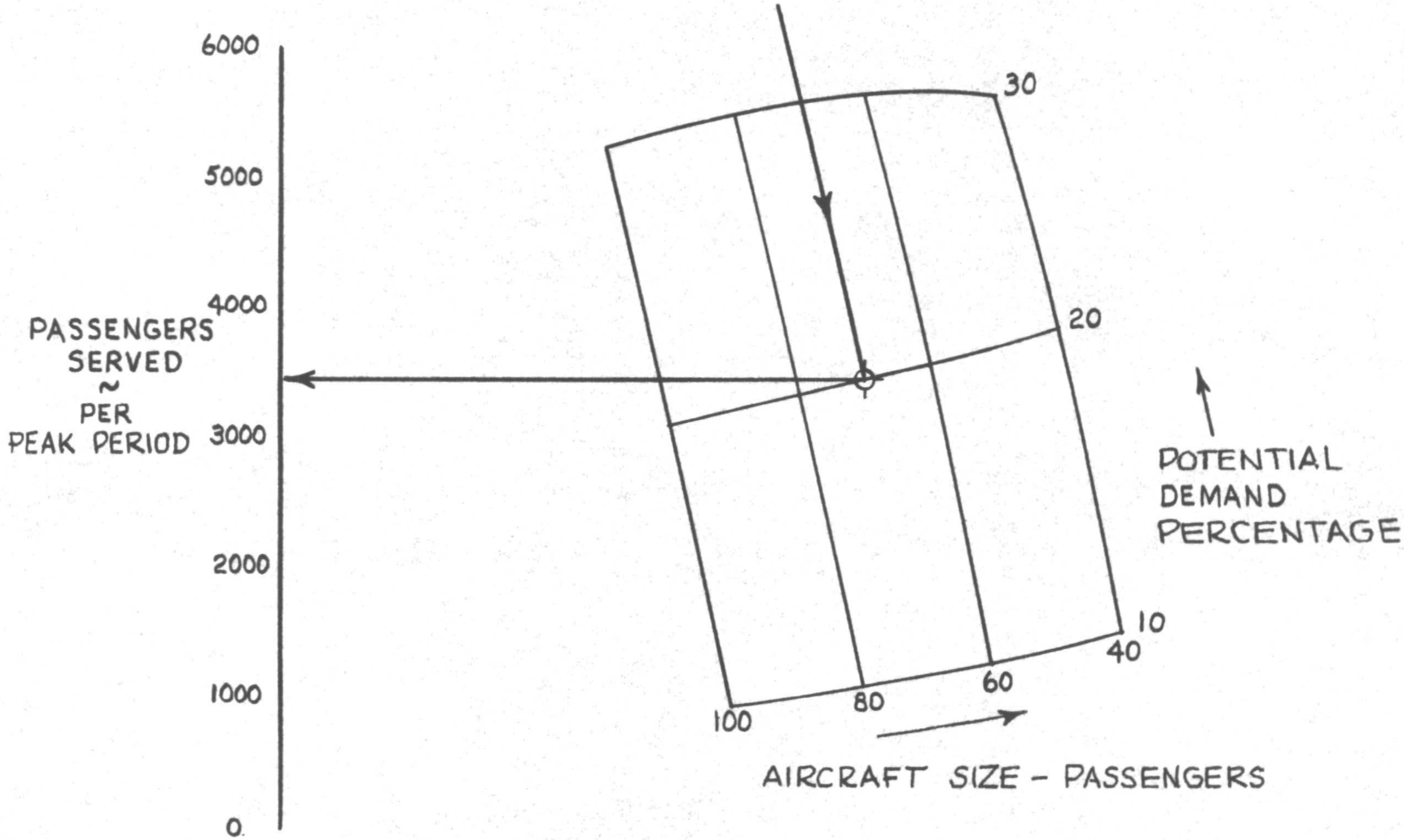

FIGURE 1.3-18. POTENTIAL PASSENGER TRAFFIC VOLUME

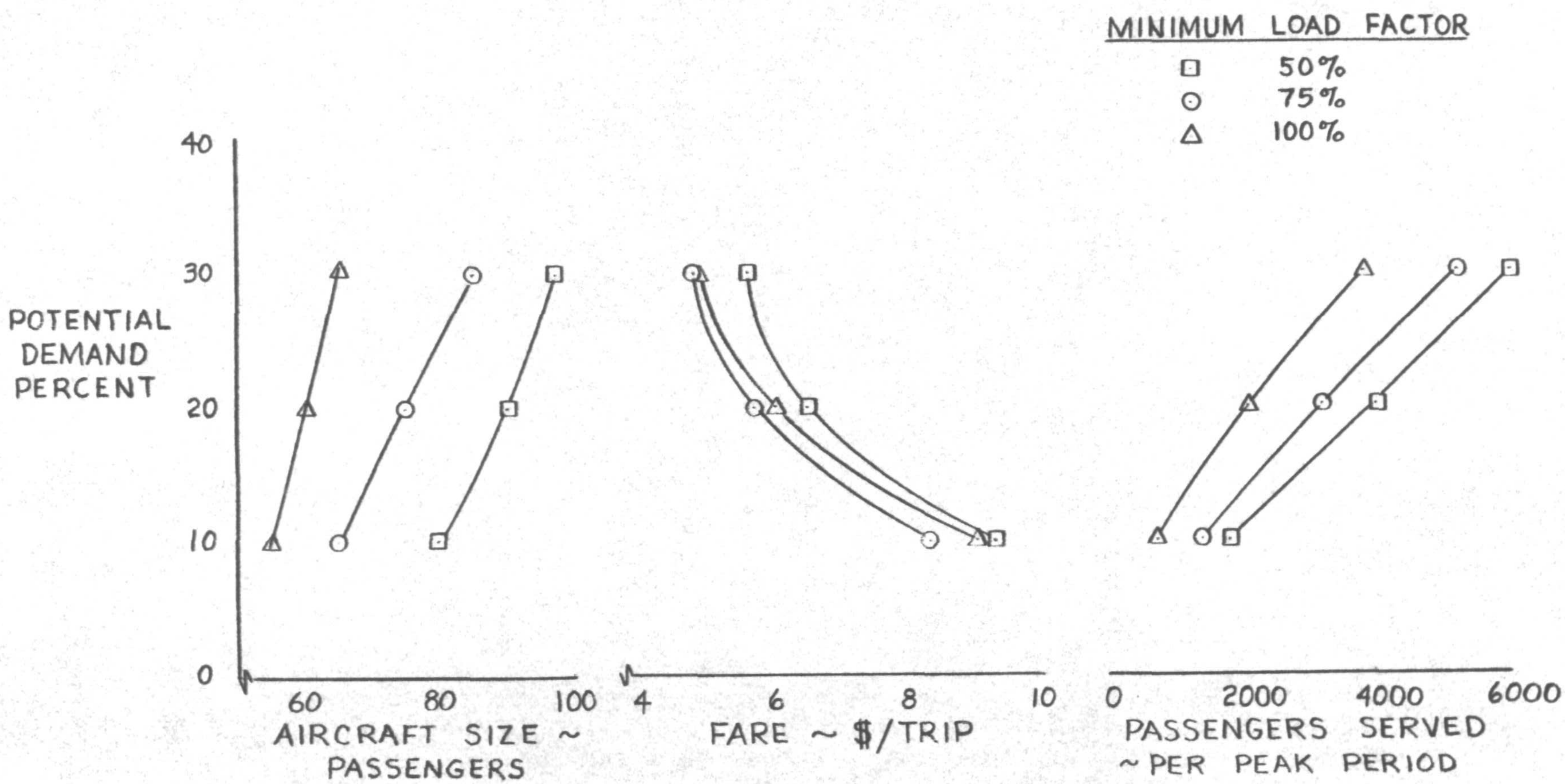

FIGURE 1.3-19. MINIMUM FARE METHOD - STEP 3

concept and each minimum load factor, for variations in the aircraft size as a function of number of aircraft, schedule time, and fare as illustrated on Figure 1.3-16. To use this method, you enter this curve where the fare line becomes tangent to a projected fare line. This point represents the minimum fare point and is projected across to the schedule time line and the number of aircraft line and across to the aircraft size. This procedure is followed for each of the minimum load factor curves. Each of these data points from each of the three different load factor curves is then plotted as illustrated on Figure 1.3-17. The fare is plotted as a function of the number of aircraft, schedule time, and aircraft size for the three different demands and load factors.

As the aircraft size increases, the number of potential passengers served is reduced due to the fact that a larger aircraft can not afford to serve those terminals which only project a small passenger demand. These potential flights are then dropped which results in a reduced number of passengers served. Figure 1.3-18 is an illustration of this potential passenger traffic volume effect. Taking the data points from Figure 1.3-12 and projecting them onto Figure 1.3-18, you can then solve for the actual number of passengers served during the three hour peak period. The resulting points are then plotted as shown on Figure 1.3-19. The potential demand percentage is plotted against aircraft size, fare, and passengers served during the three hour peak period. This is done for each of the minimum load factors. Figures 1.3-20 through 1.3-22 are illustrative figures for the 20 minute schedule method of analysis. In using this technique, you enter the schedule time at 20 minutes and project across to the fare and number of aircraft lines plus across to the aircraft size scale. This technique is repeated for each of the load factors as in the minimum fare method of analysis. Figures 1.3-21 and 1.3-22 are developed in the same manner as that used in the minimum fare technique. The final step consists of cross plotting the fare against the passengers served during the peak period for both methods of analysis. Figure 1.3-23 presents the resulting comparison of the two methods.

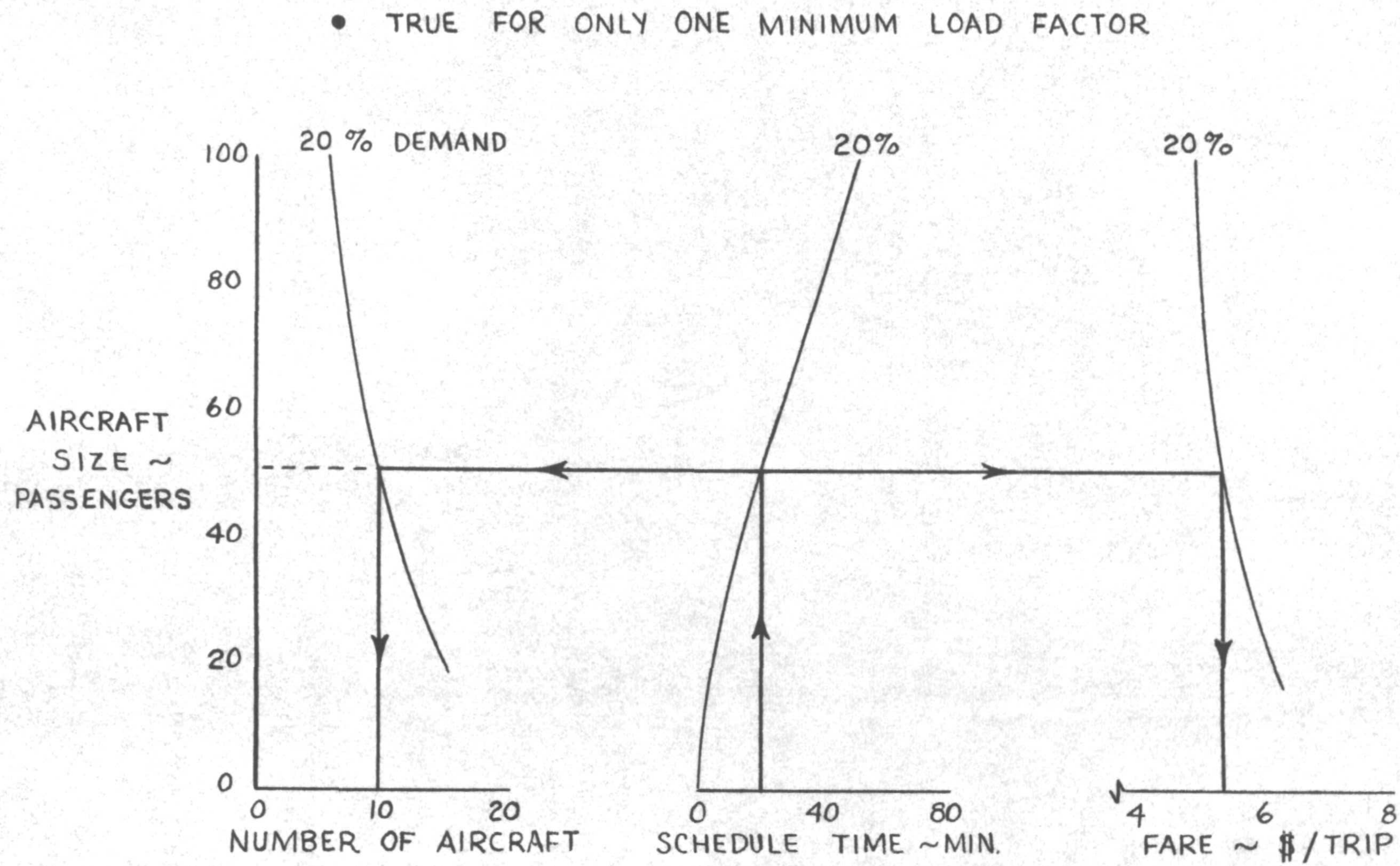

FIGURE 1.3-20. 20 MINUTE SCHEDULE METHOD - STEP 1

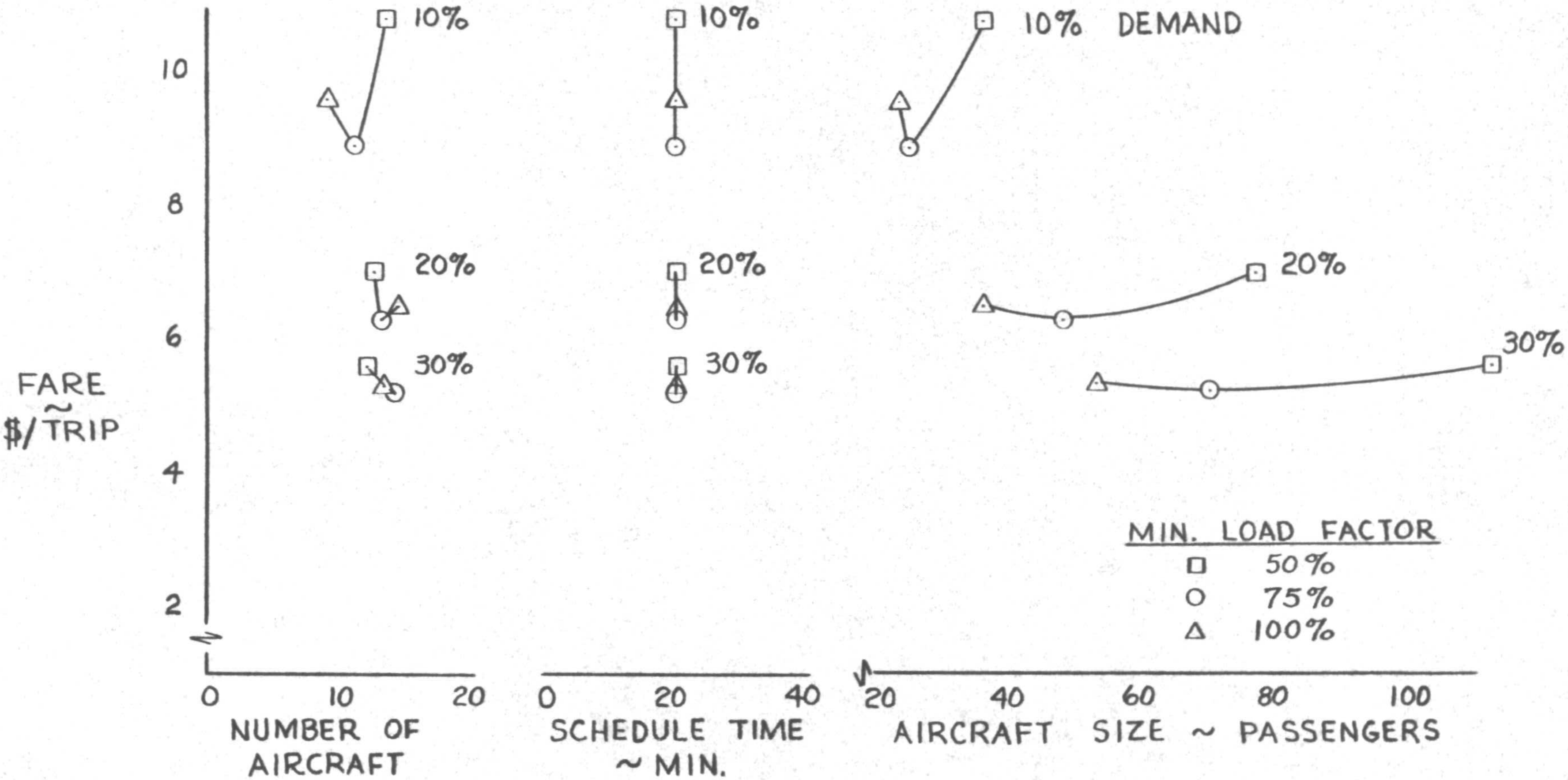

FIGURE 1.3-21. 20 MINUTE SCHEDULE METHOD - STEP 2

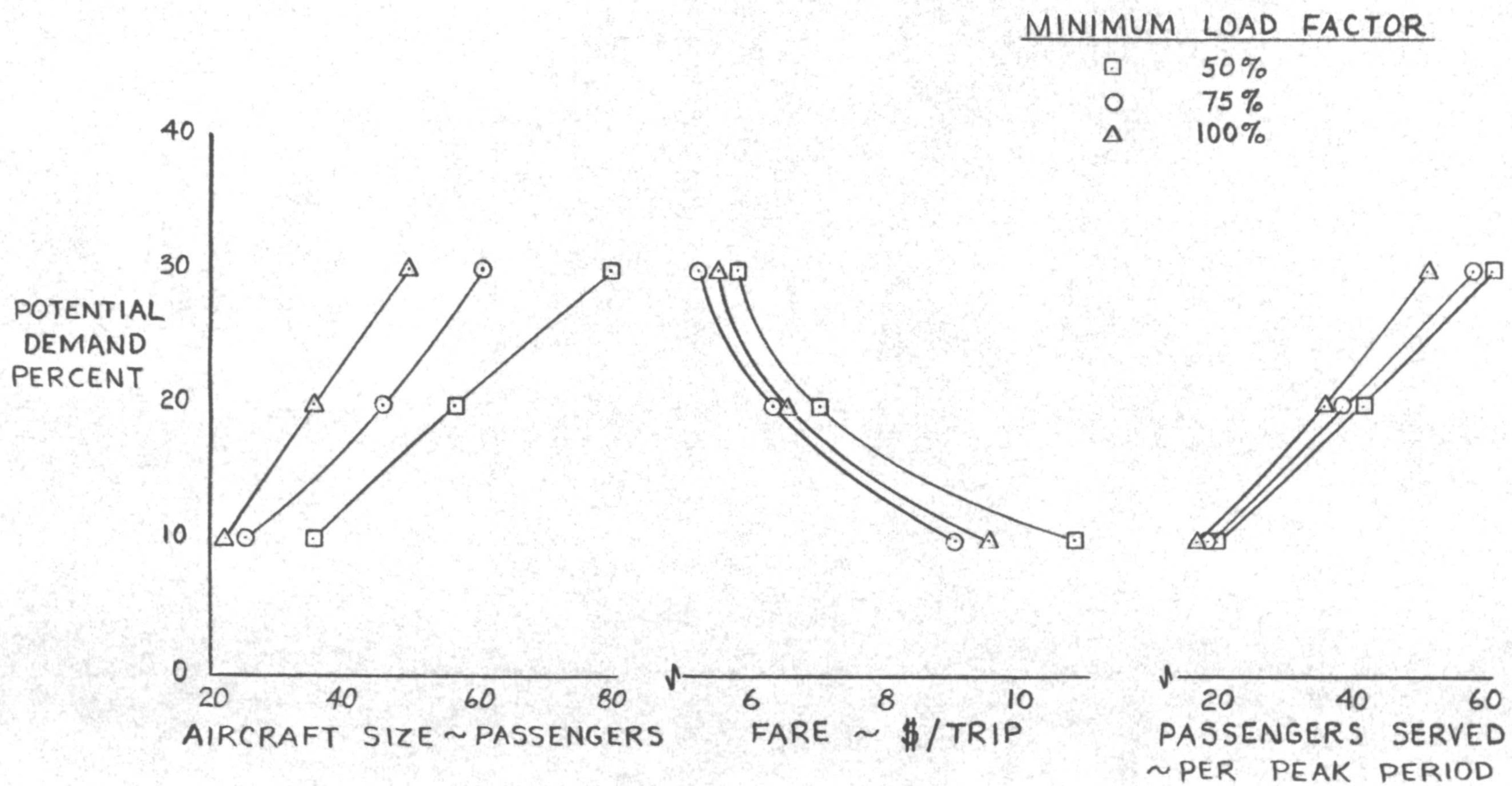

FIGURE 1.3-22. 20 MINUTE SCHEDULE METHOD - STEP 3

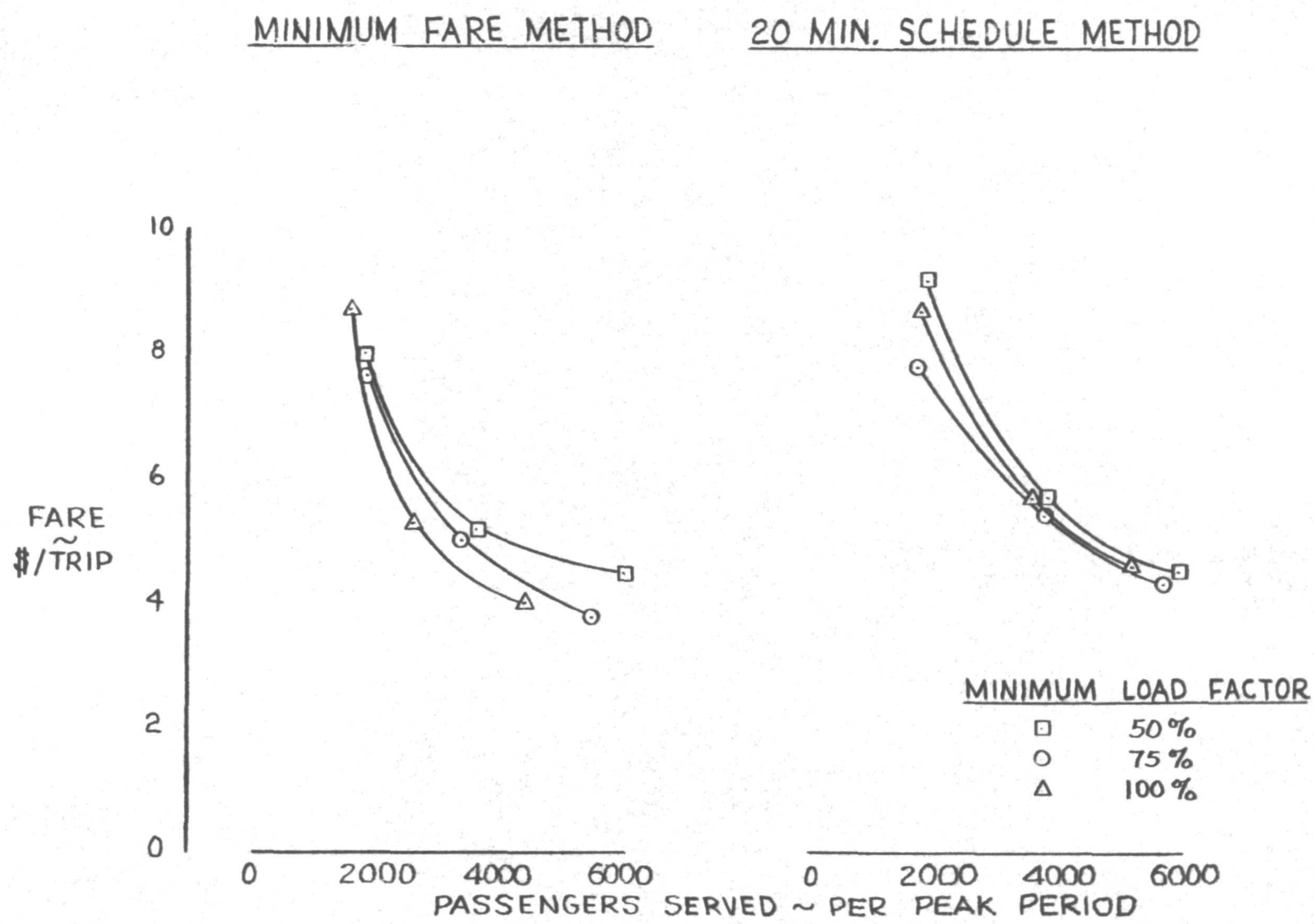

FIGURE 1.3-23. COMPARISON OF METHODS

As would be expected, the minimum fare method shows an optimum with a minimum load factor of 100 percent. However, in looking at the 20 minute schedule method, it is noted that the lower line is the 75 percent load factor line. This effect occurs because in order to maintain a 20 minute schedule it is necessary to offload the aircraft and increase the fleet size to meet this time table. These bottom lines from each of the methods of analysis represents the locus of optimum points for each of the concepts under study. It is this final line which is used to make the final stacking of the concepts for evaluation and selection (see Section 1.4). Working backwards from this line, the exact characteristics of any particular concept can be determined.

The final stacking figures which are shown and discussed in Section 1.4 were derived from Figures 1.3-24 through 1.3-43. These twenty figures show plots of fare versus number of passengers served per peak period for minimum fare and the 20 minute schedule for each of the ten aircraft concepts analyzed.

The twenty figures were plotted from data contained in Appendix A. Figures A-1.3-1 through A-1.3-50 consist of five curves for each of the ten concepts considered, and show plots of aircraft characteristics, system parameters and costs. These figures (as found in the Appendix A) were used to arrive, by the graphical solution technique previously described, at the solutions shown on the resulting twenty figures (Figures 1.3-24 through 1.3-43).

The fifty working curves as found in the Appendix A were plotted from the data contained on Tables A1.3-1 through A1.3-22.

In addition to these working curves for each of the concepts it is necessary to use the 1975 potential passenger traffic volume as shown in Appendix A, Figure A-1.3-51 and the 1985 potential passenger traffic volume curves (see Figure A-1.3-52). As noted earlier, by working with these curves, other methods of analysis can be done, such as fixing the fleet size and solving for the optimum line. The resulting system can then be evaluated against the other methods. These curves graphically represent the entire matrix of the required investigation and a great deal of additional information is available through working with these curves. As

cautioned earlier, these curves will not predict the number of passengers served for a given fare. They will only give the fare if X number of passengers are served.

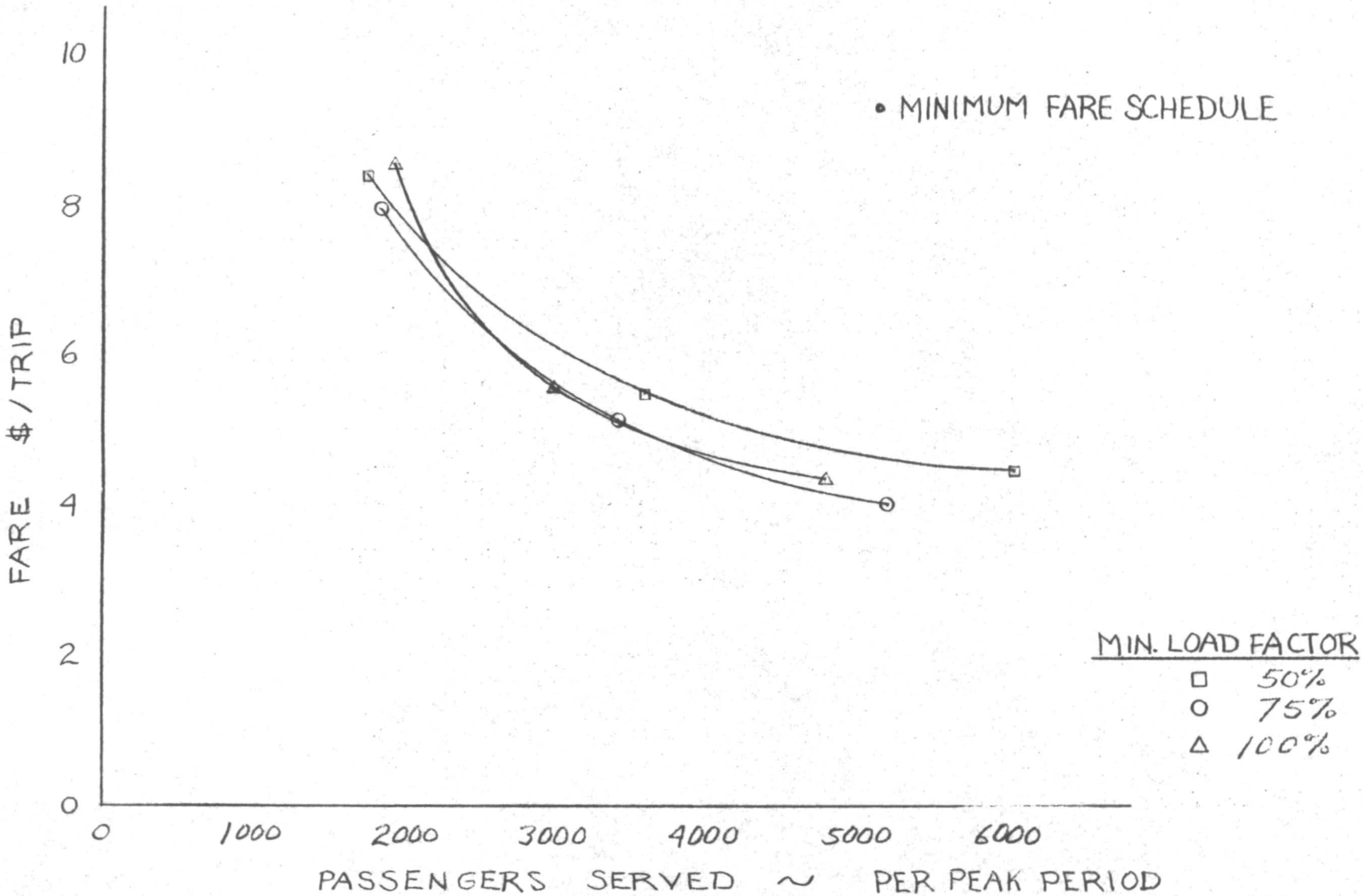

Figure 1.3-24 Minimum Fare Effect on the 1975 CTOL

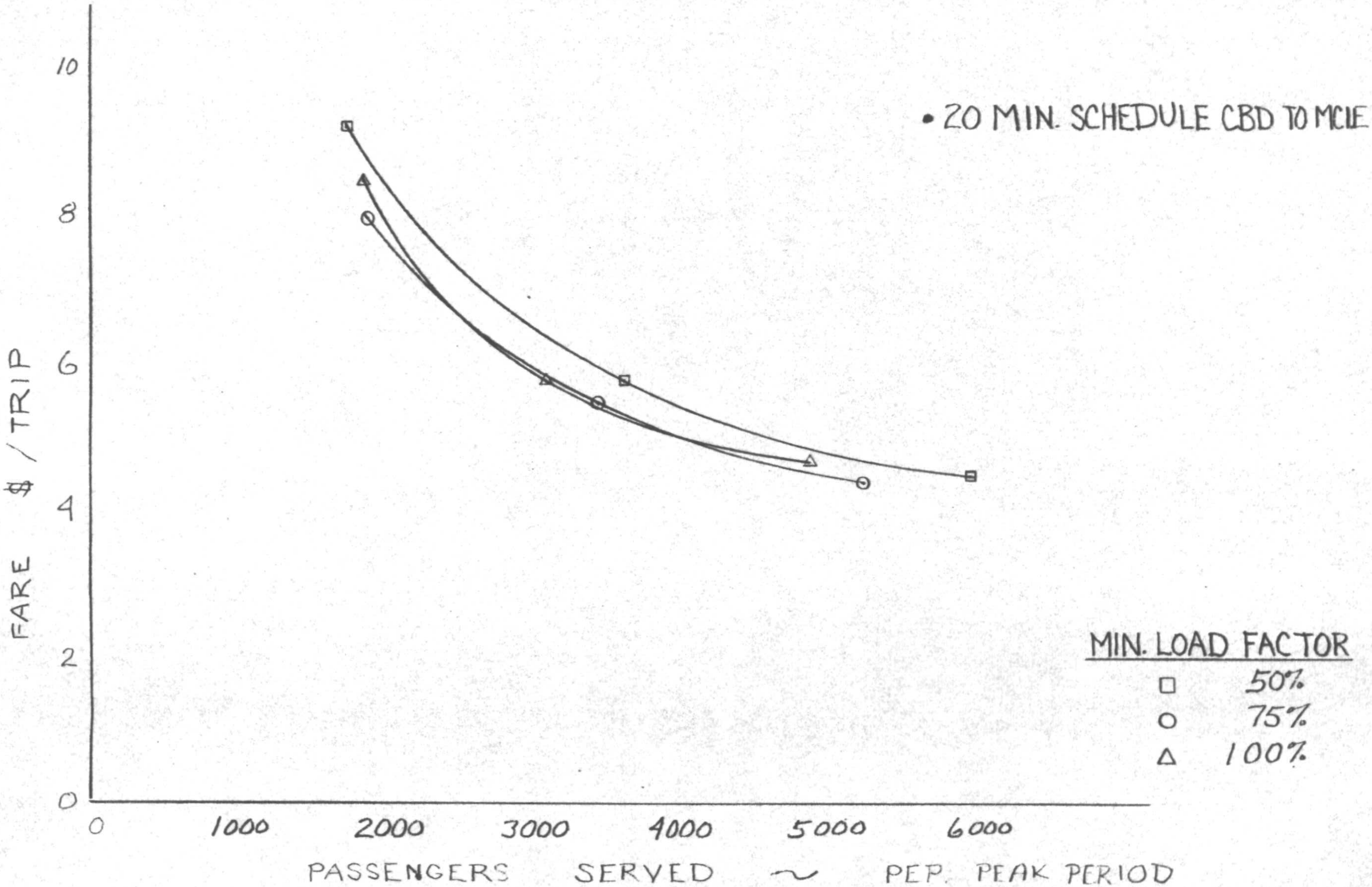

Figure 1.3-25. 20-Minute Schedule Effect on the 1975 CTOL

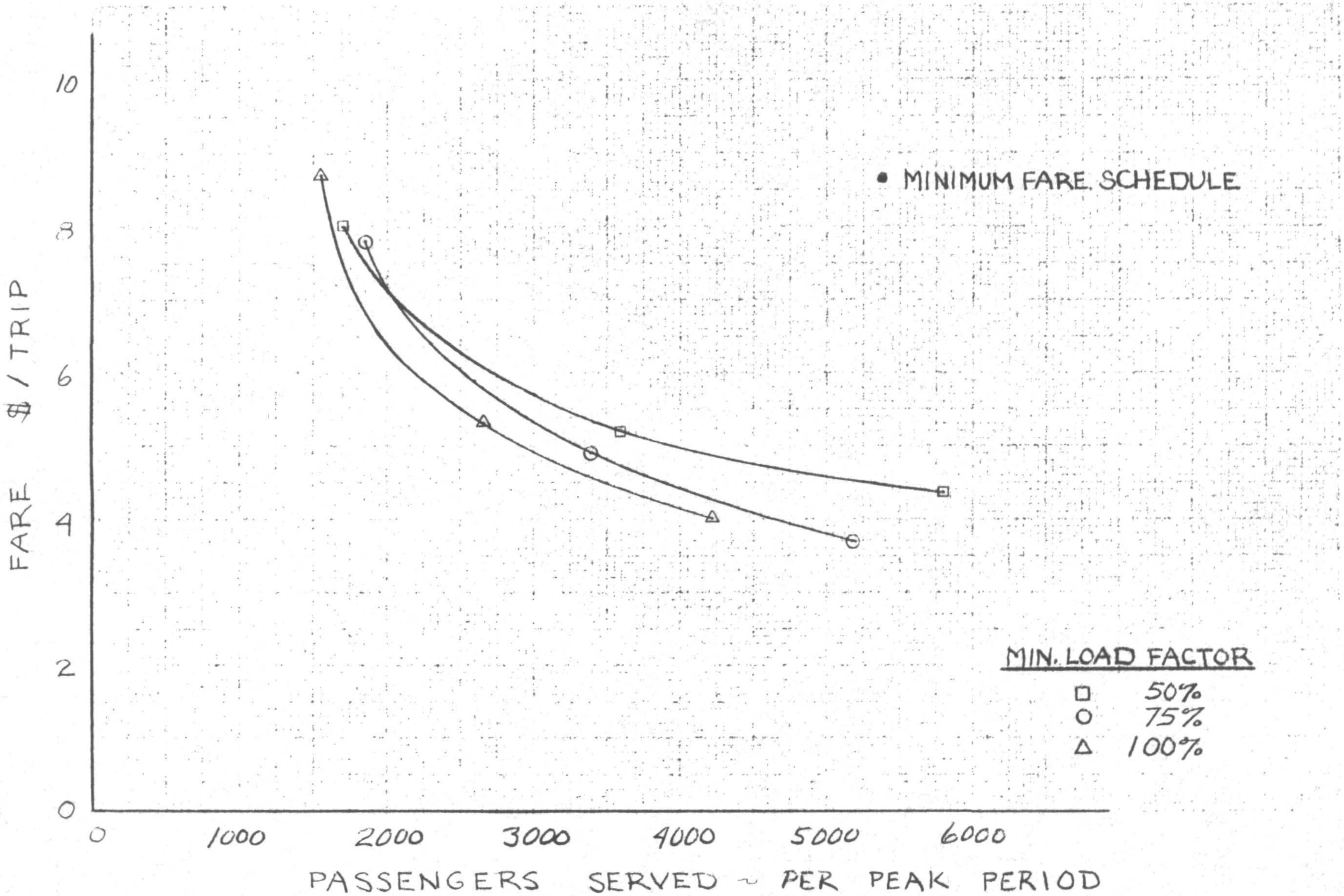

Figure 1.3-26 Minimum Fare Effect on the 1975 Deflected Slipstream STOL

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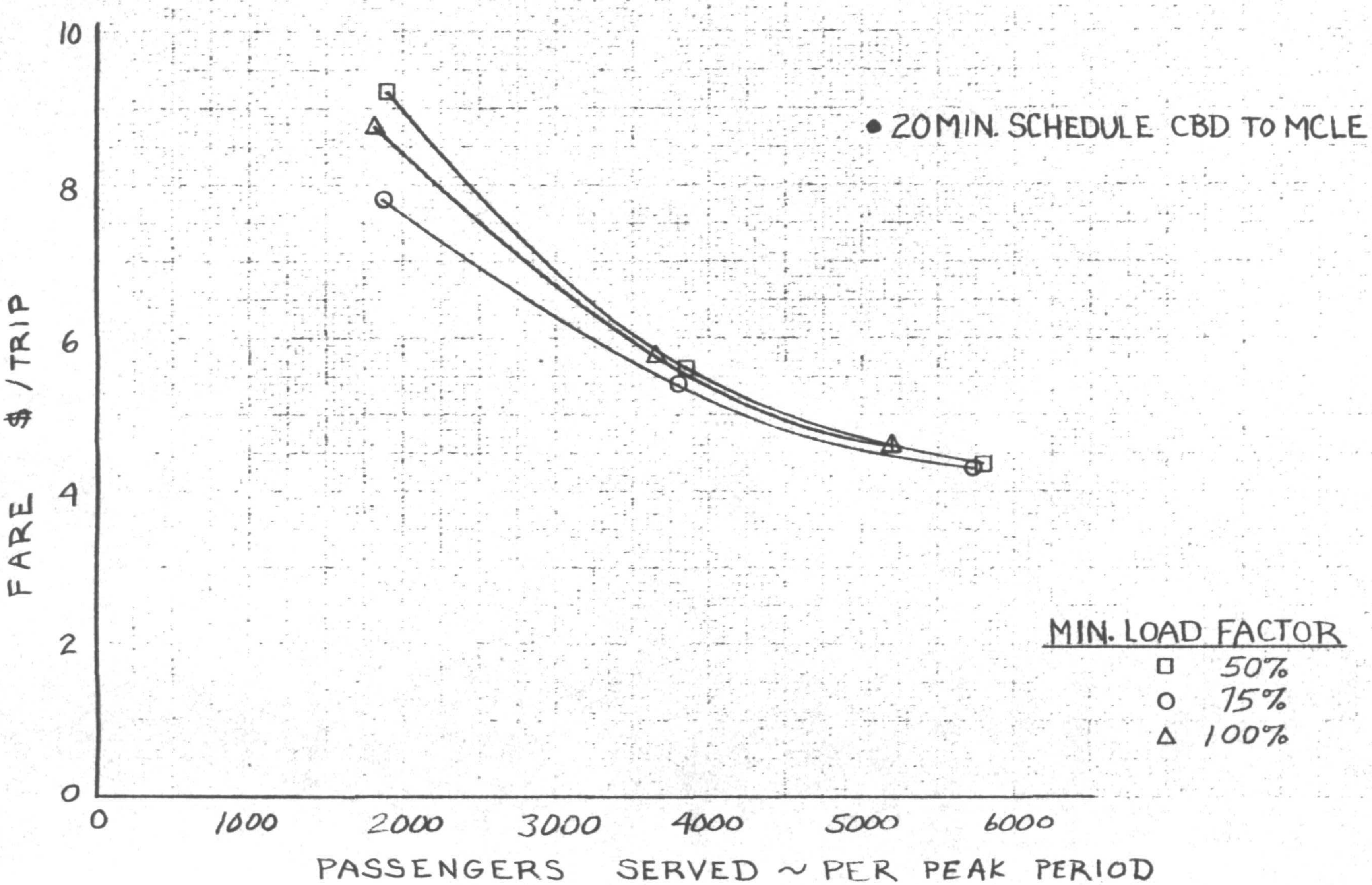


Figure 1.3-27 20-Minute Schedule Effect on the 1975 Deflected Slipstream STOL

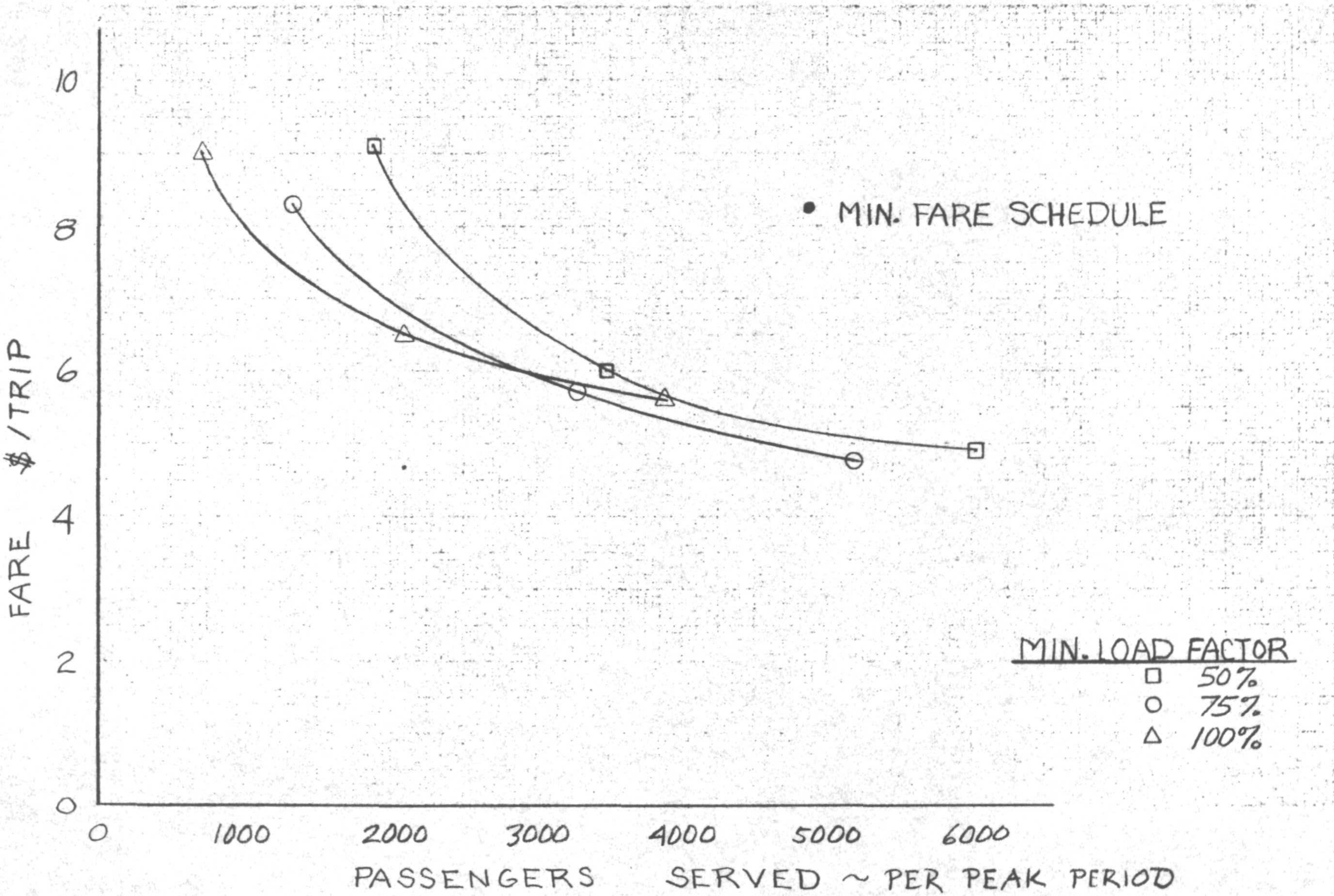


Figure 1.3-28 Minimum Fare Effect on the 1975 Tilt Wing VTOL

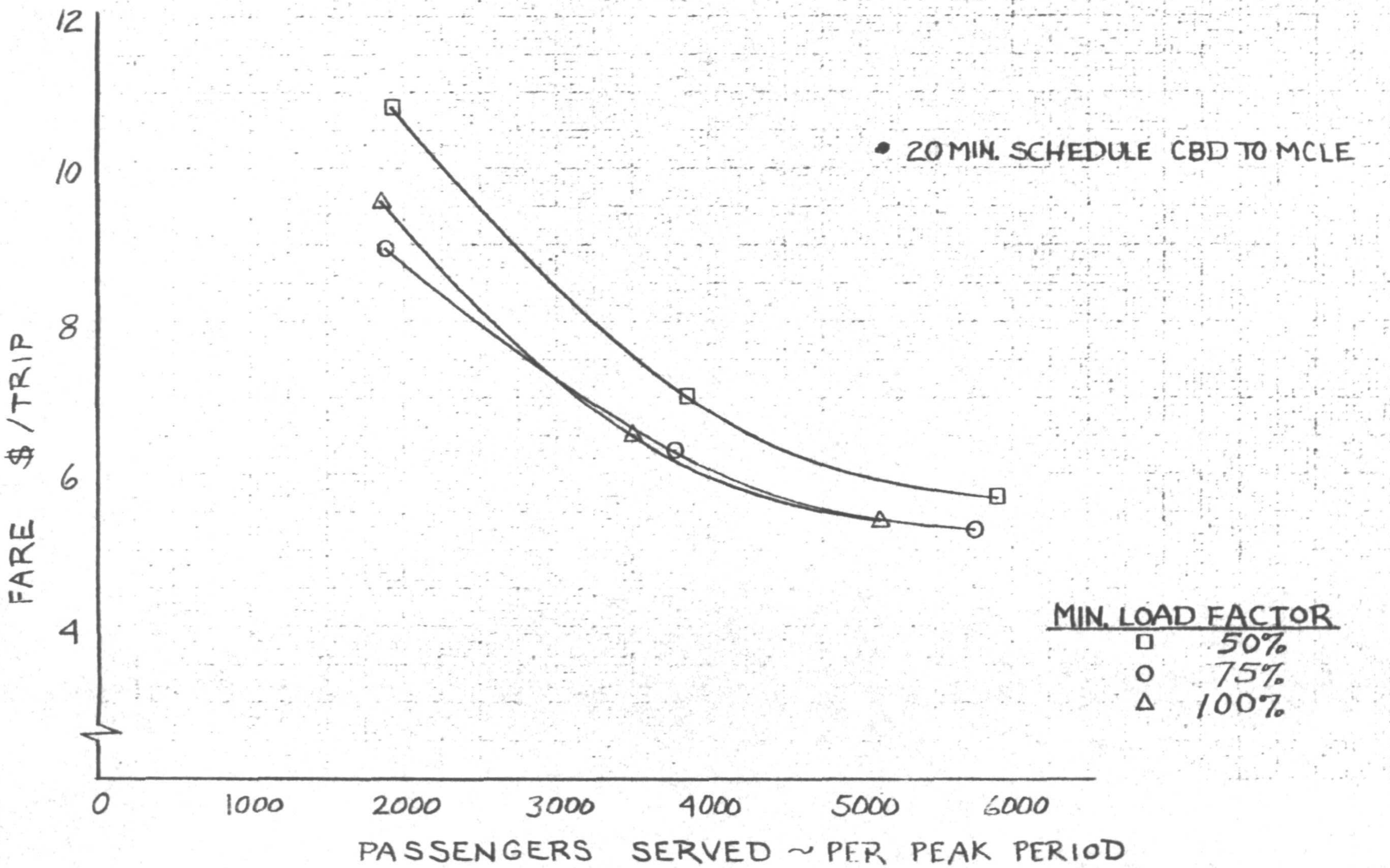


Figure 1.3-29 20-Minute Schedule Effect on the 1975 Tilt Wing VTOL

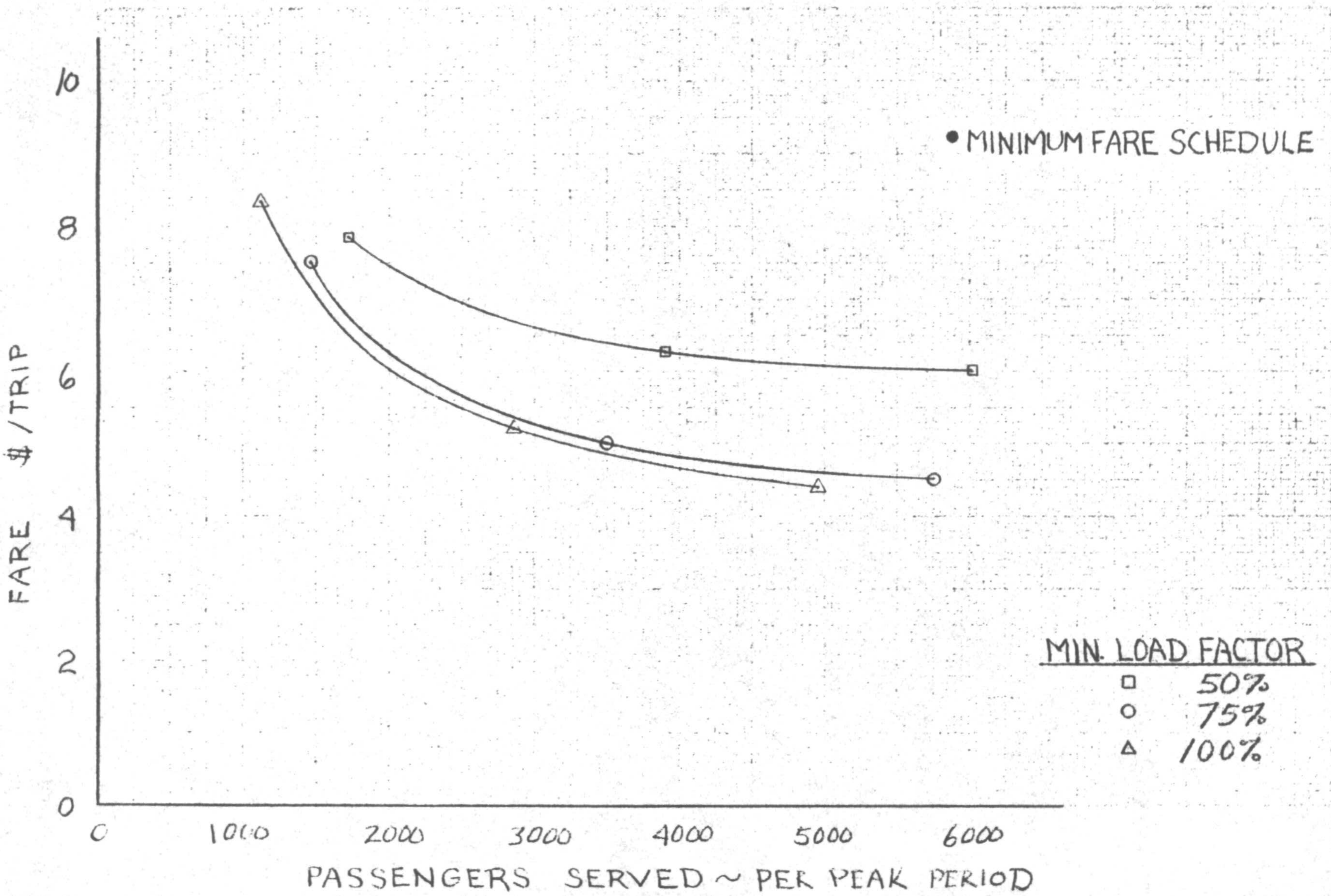


Figure 1.3-30 Minimum Fare Effect on the 1975 VTOL Compound Helicopter

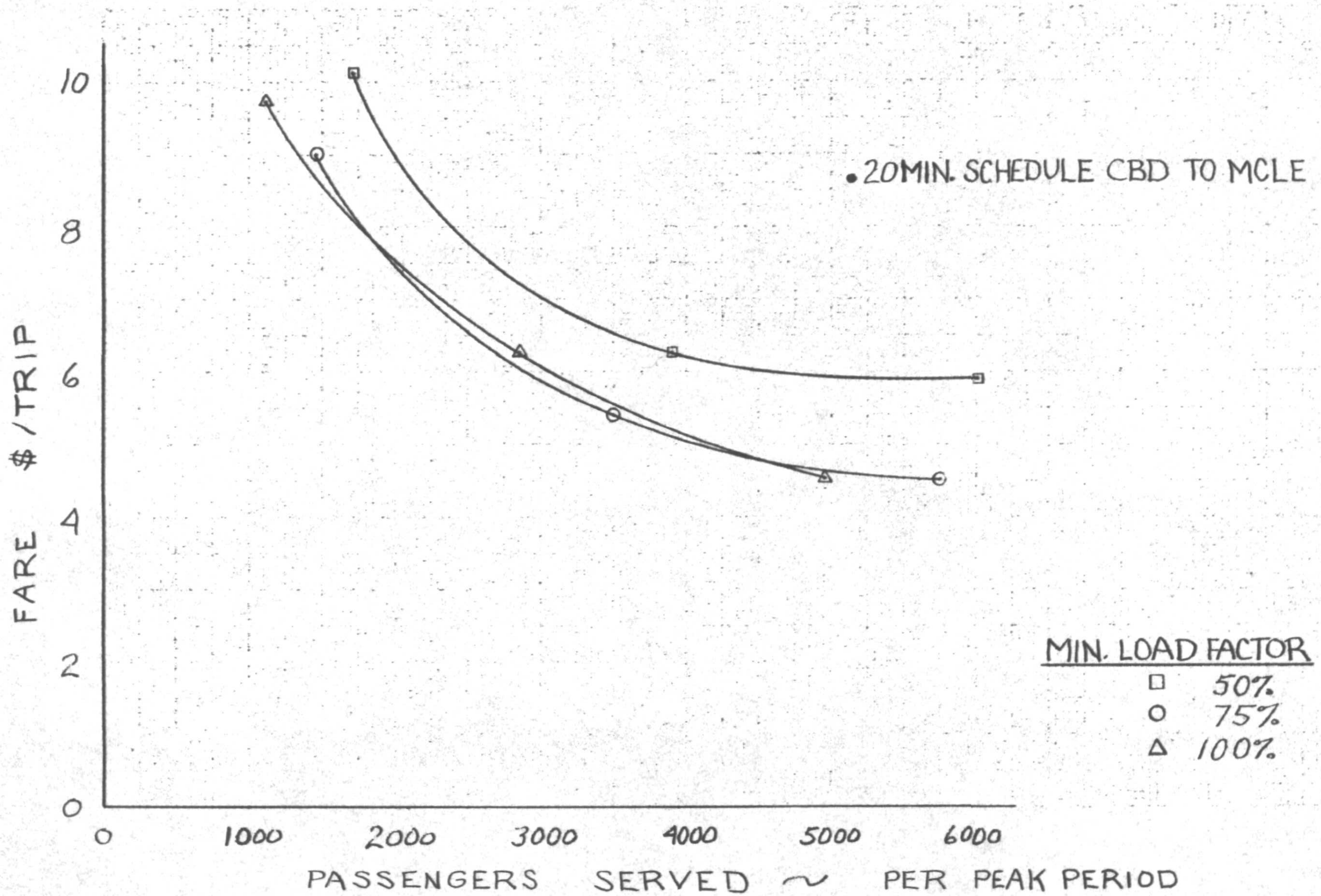


Figure 1.3-31 20-Minute Schedule Effect on the 1975 VTOL Compound Helicopter

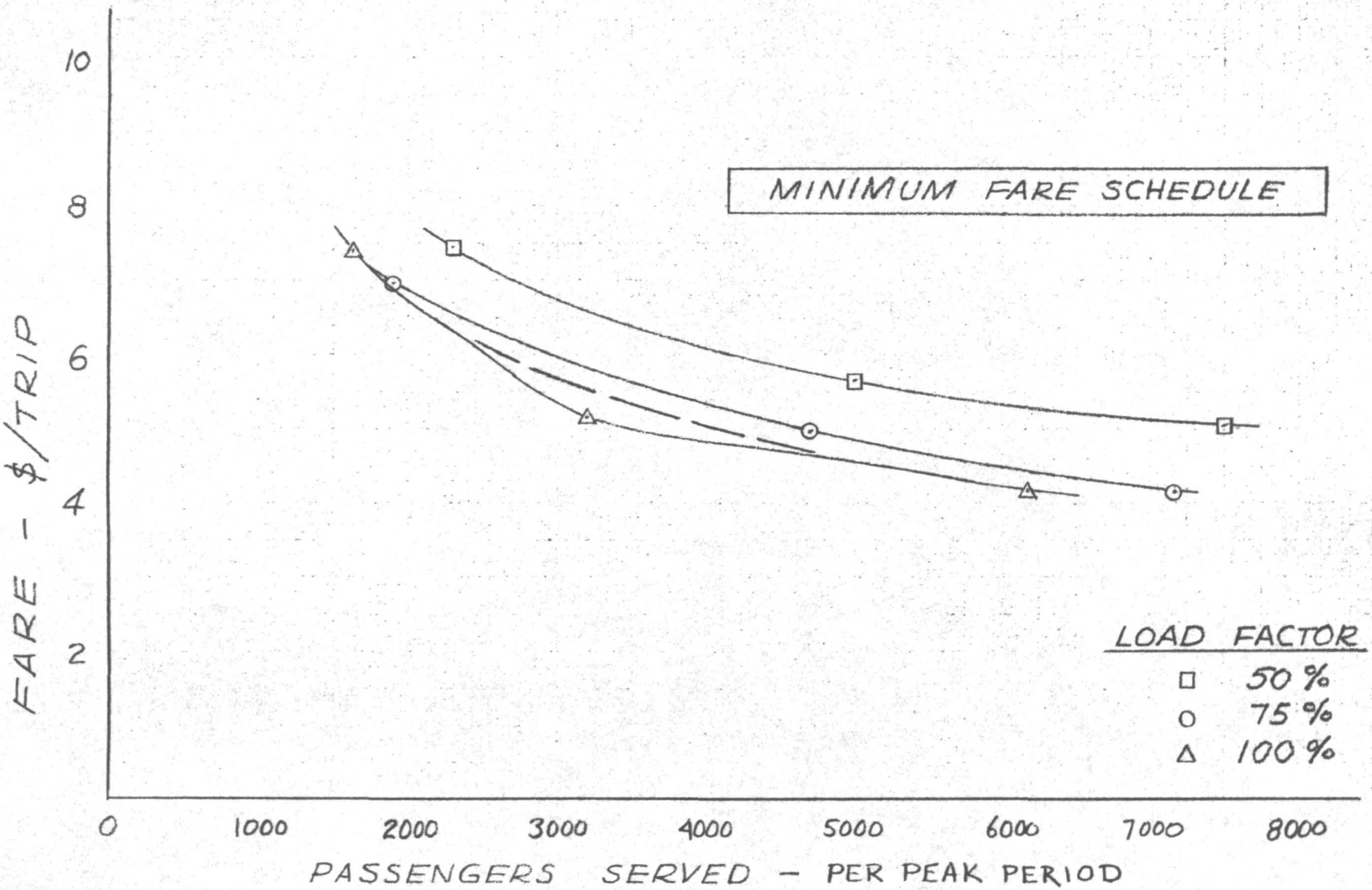


Figure 1.3-32 Minimum Fare Effect on the 1985 CTOL

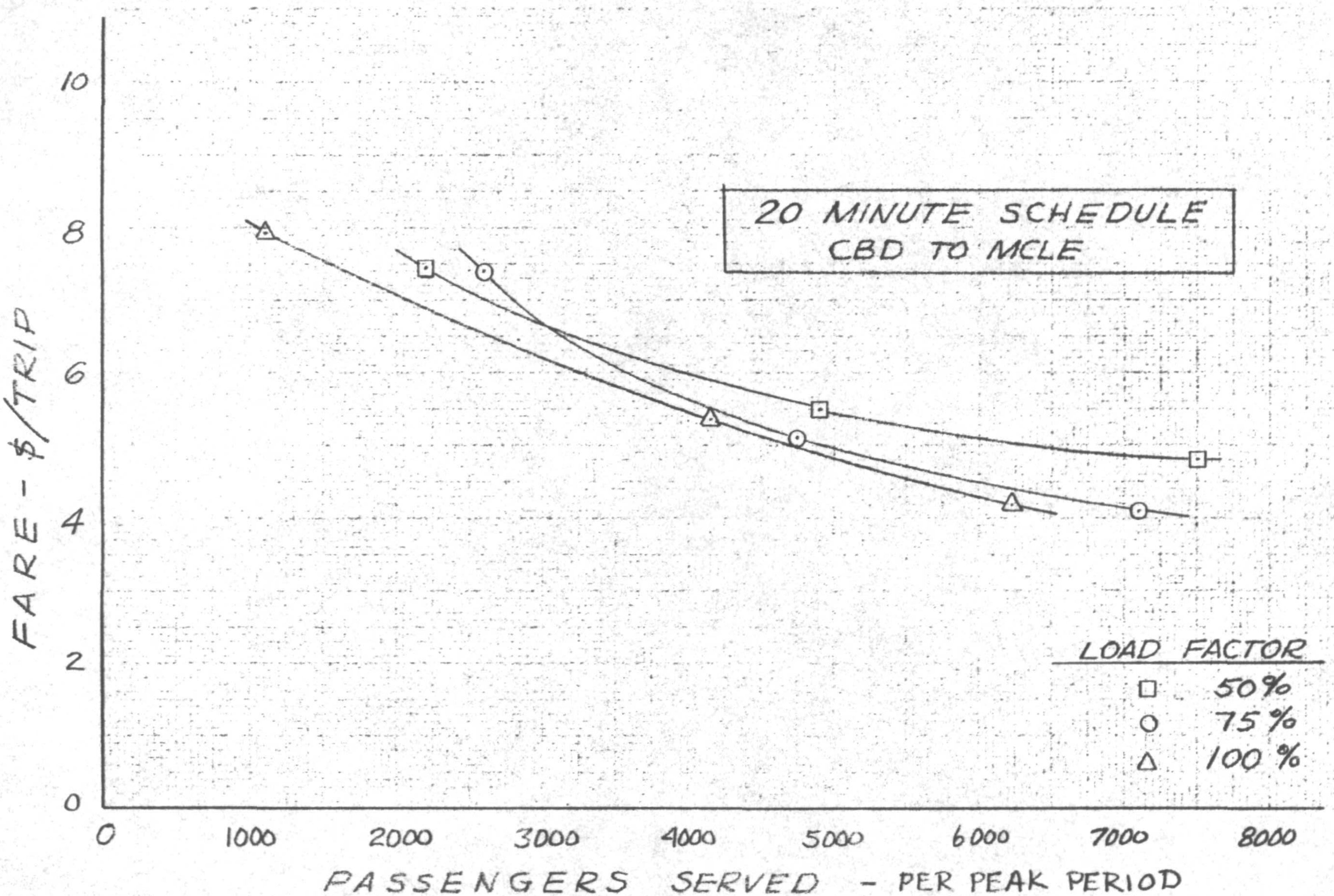


Figure 1.3-33 20-Minute Schedule Effect on the 1985 CTOL

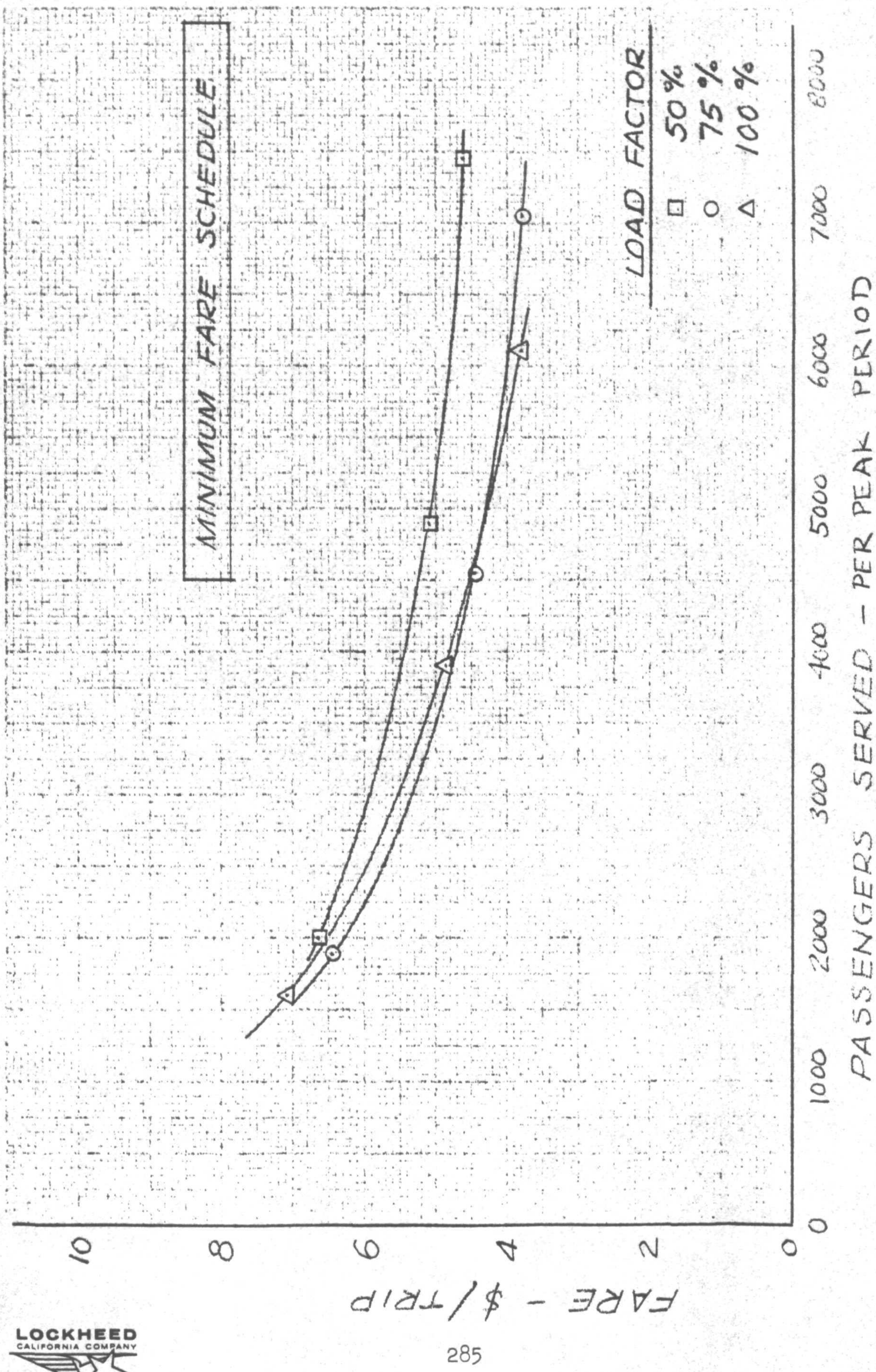


Figure 1.3-34 Minimum Fare Effect on the 1985 Deflected Slipstream STOL

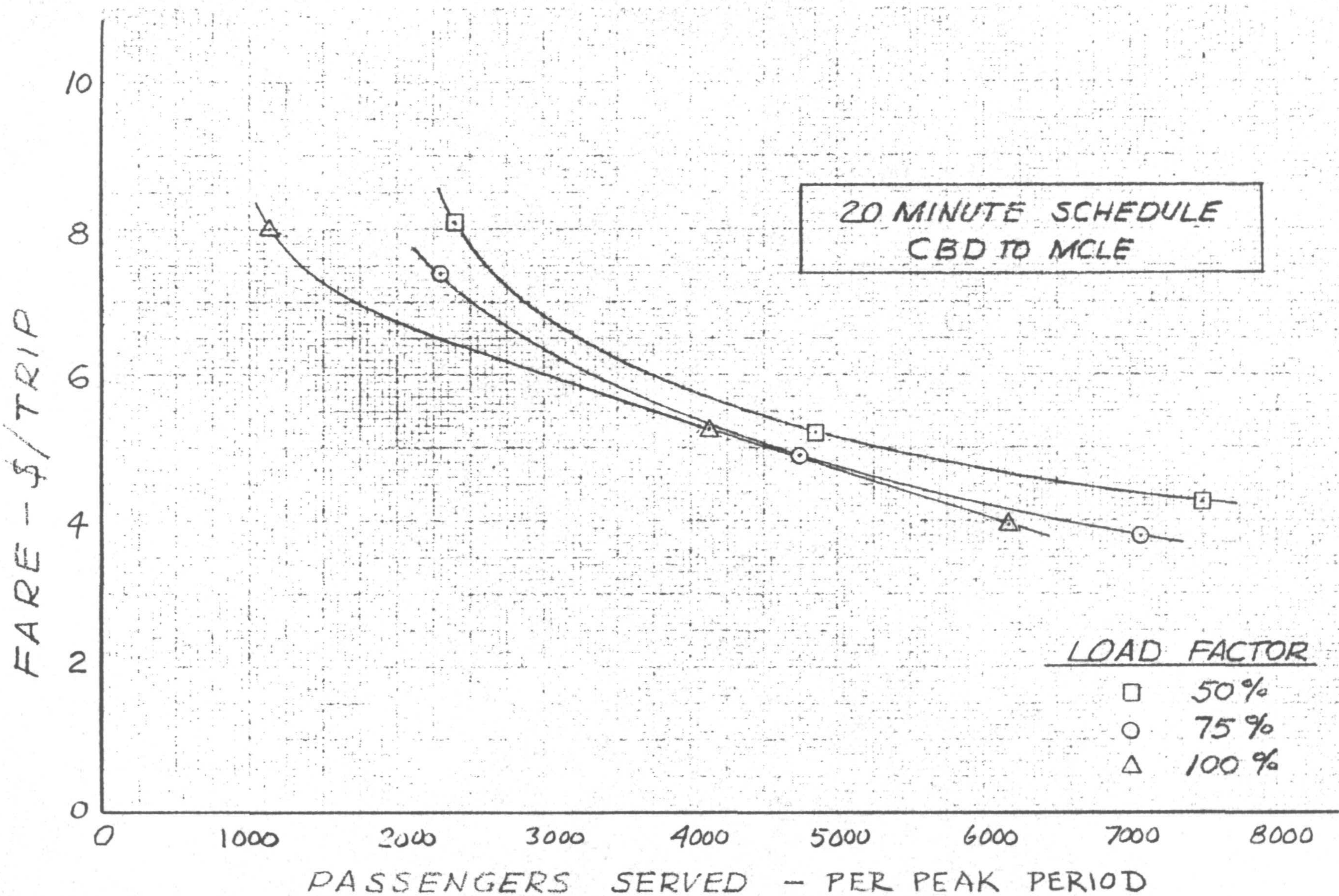


Figure 1.3-35 20-Minute Schedule Effect on the 1985 Deflected Slipstream STOL

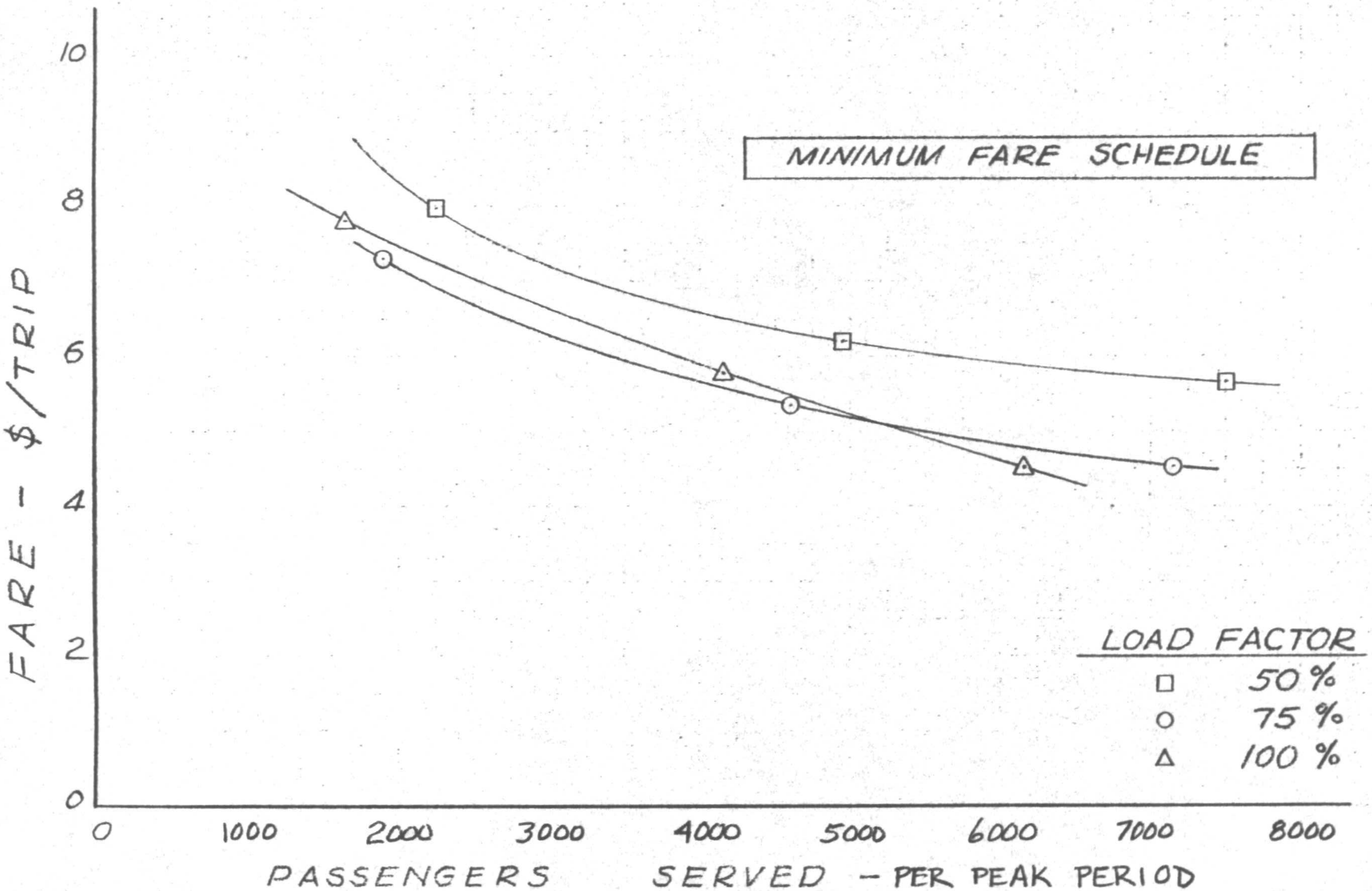


Figure 1.3-36 Minimum Fare Effect on the 1985 Augmentor Wing STOL

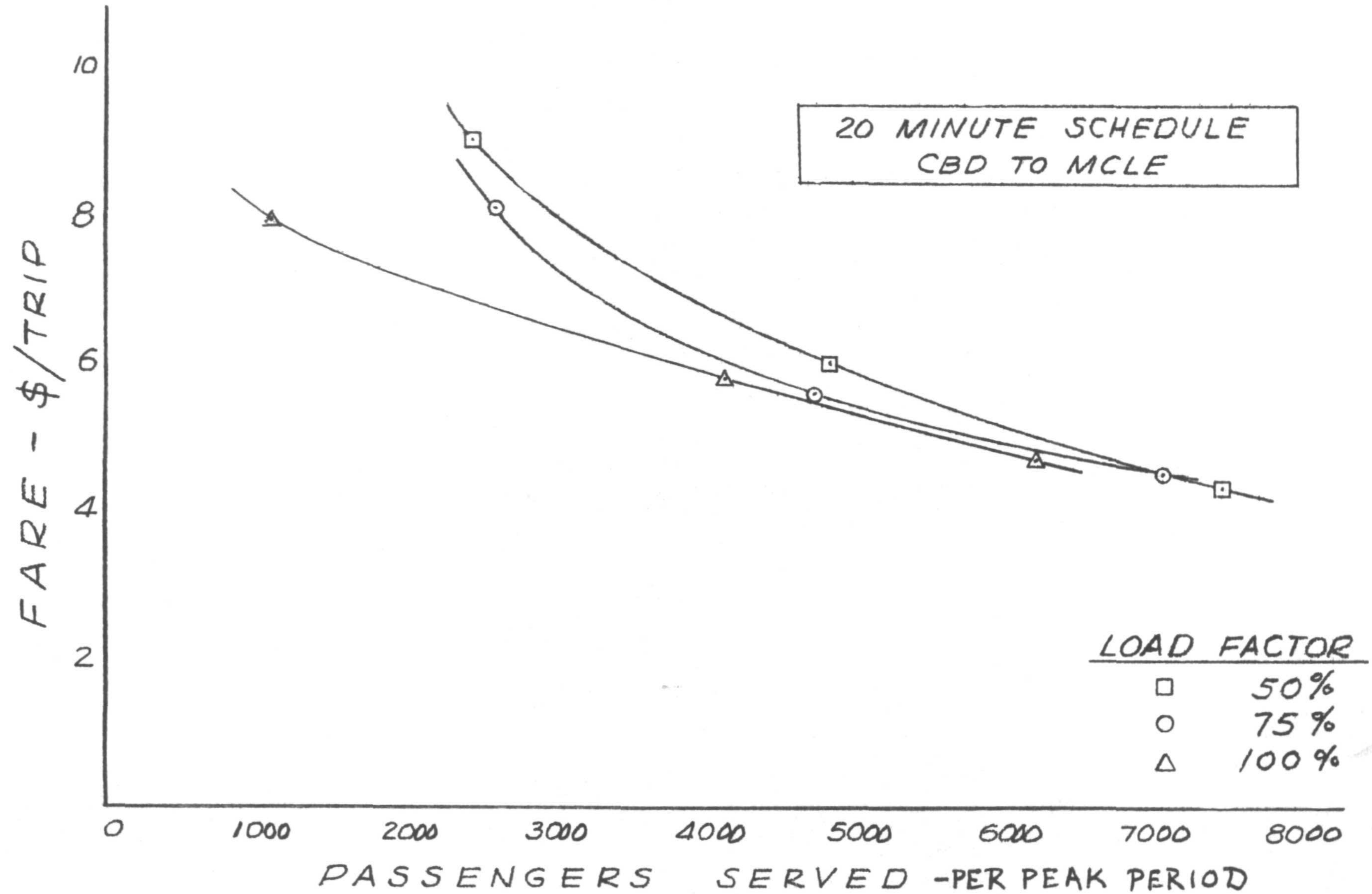


Figure 1.3-37 20-Minute Schedule Effect on the 1985 Augmentor Wing STOL

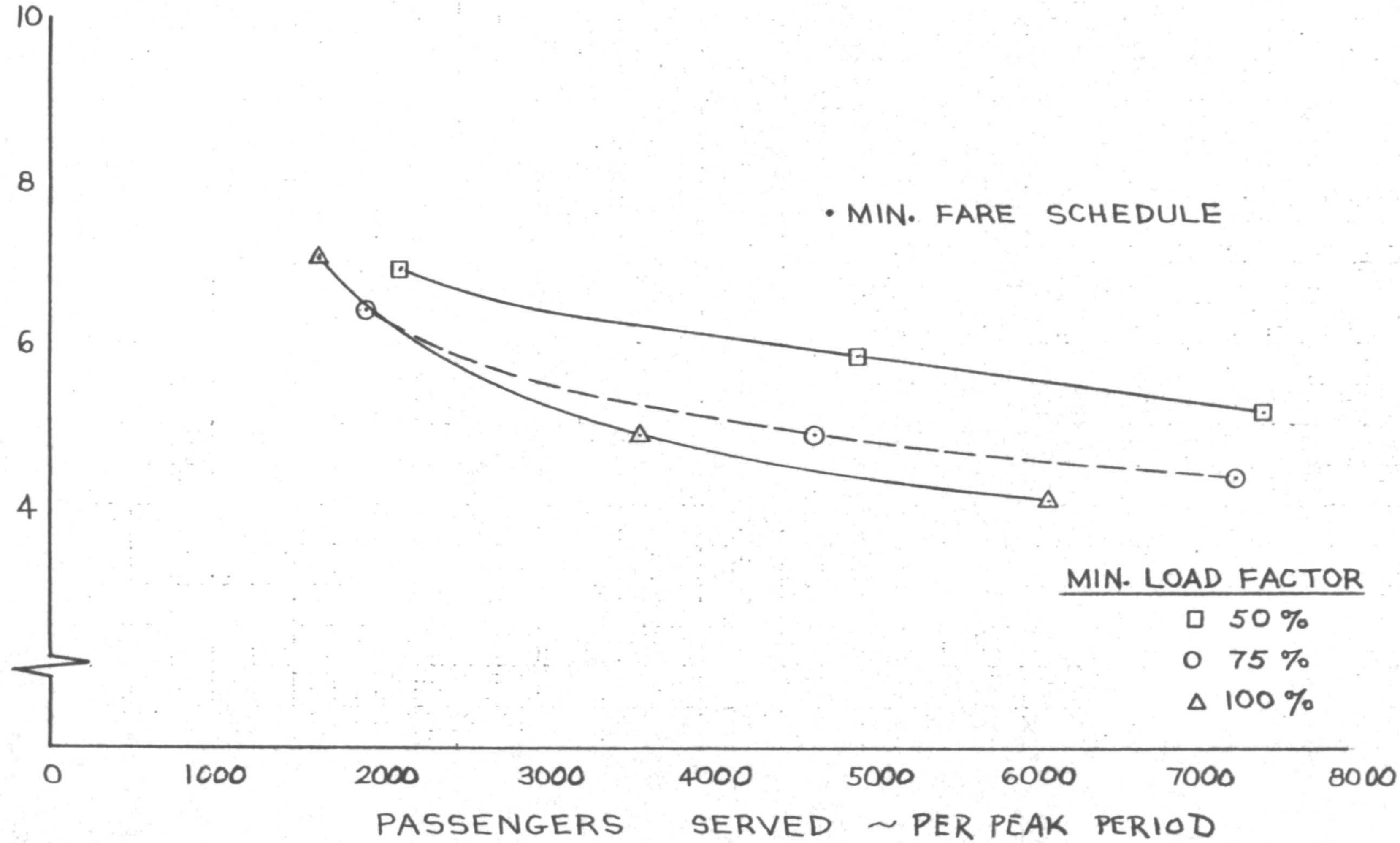


Figure 1.3-38 Minimum Fare Effect on the 1985 Autogyro STOL

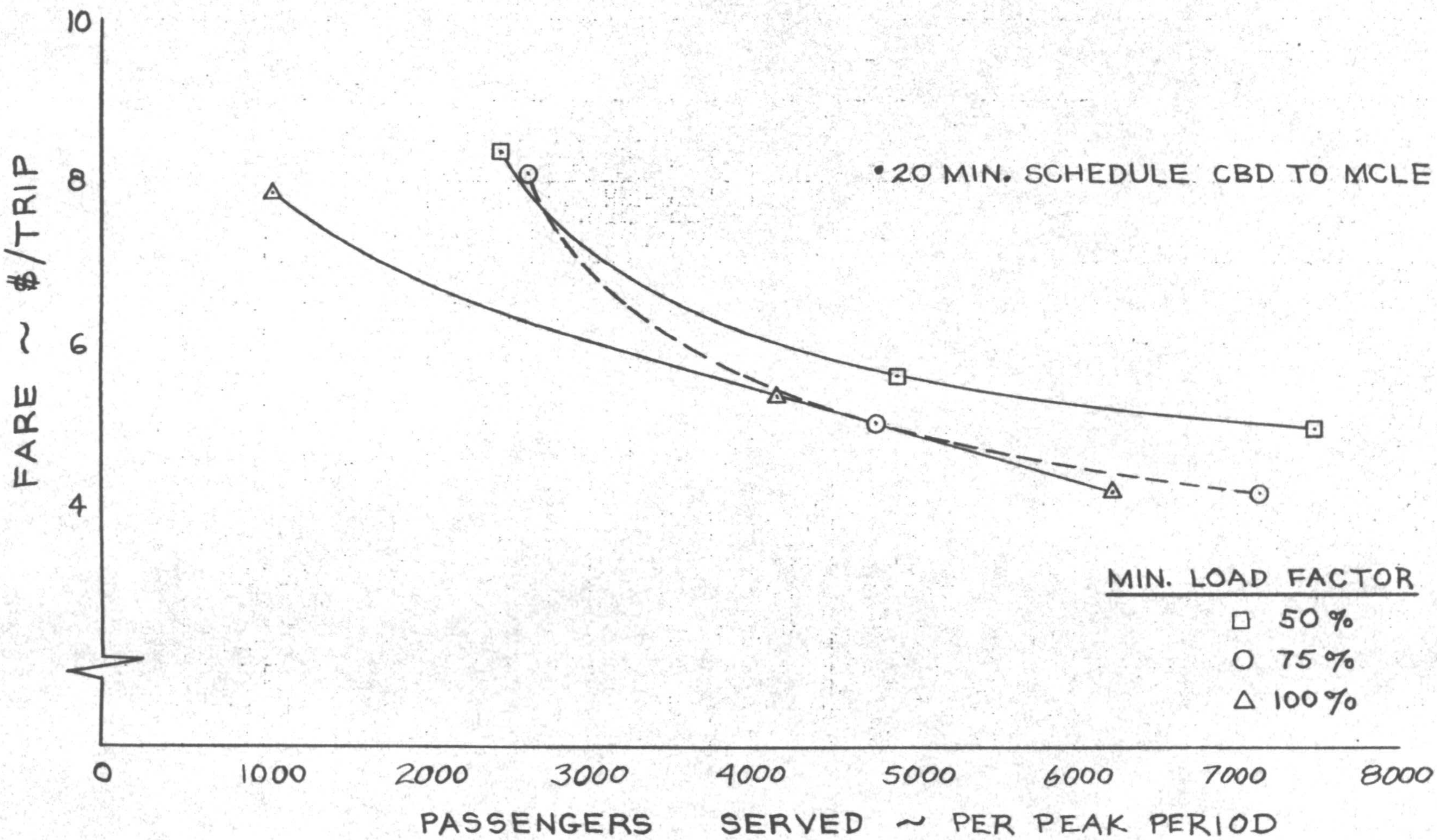


Figure 1.3-39 20-Minute Schedule Effect on the 1985 Autogyro STOL

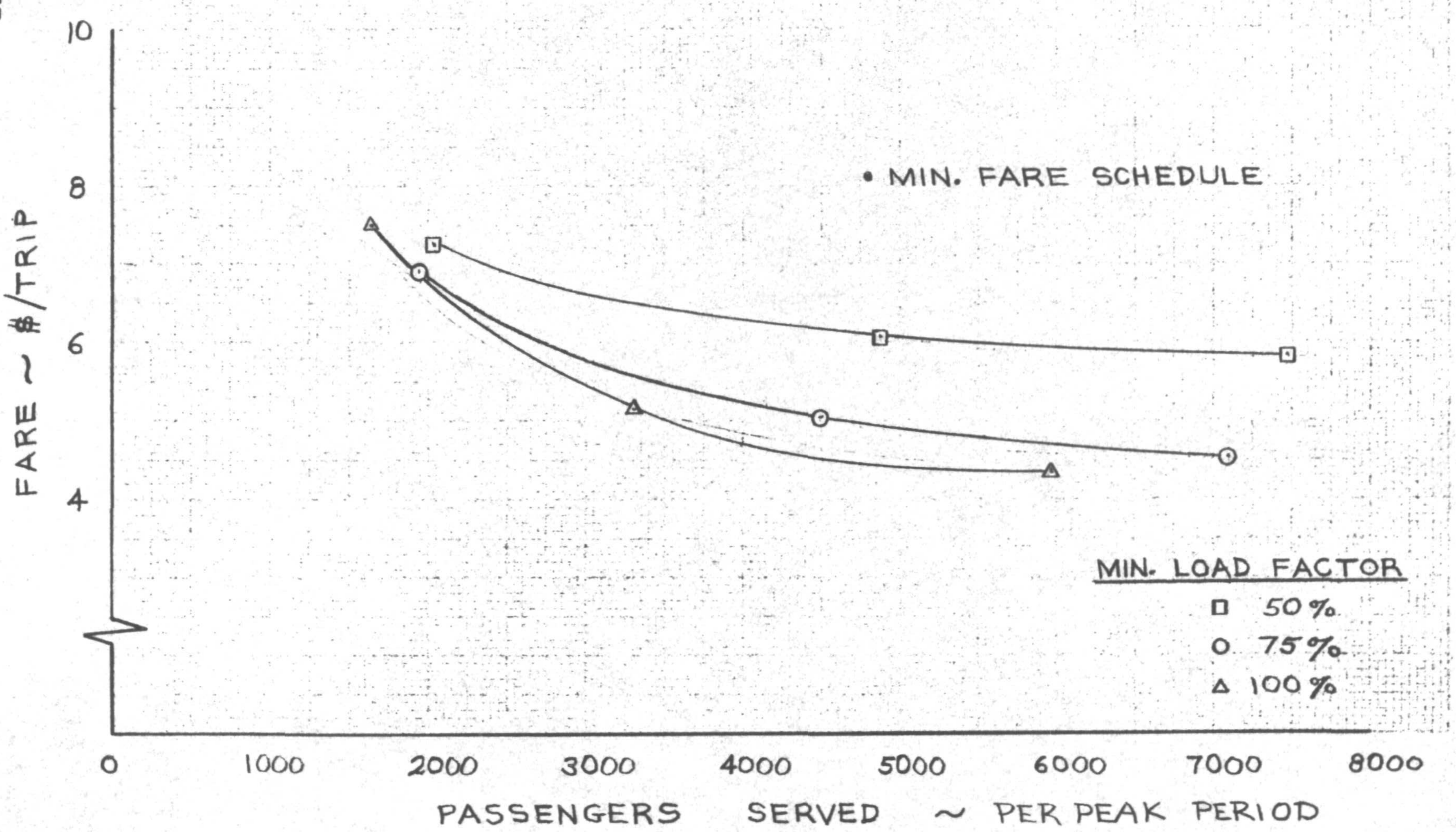


Figure 1.3-40 Minimum Fare Effect on the 1985 Tilt Wing VTOL

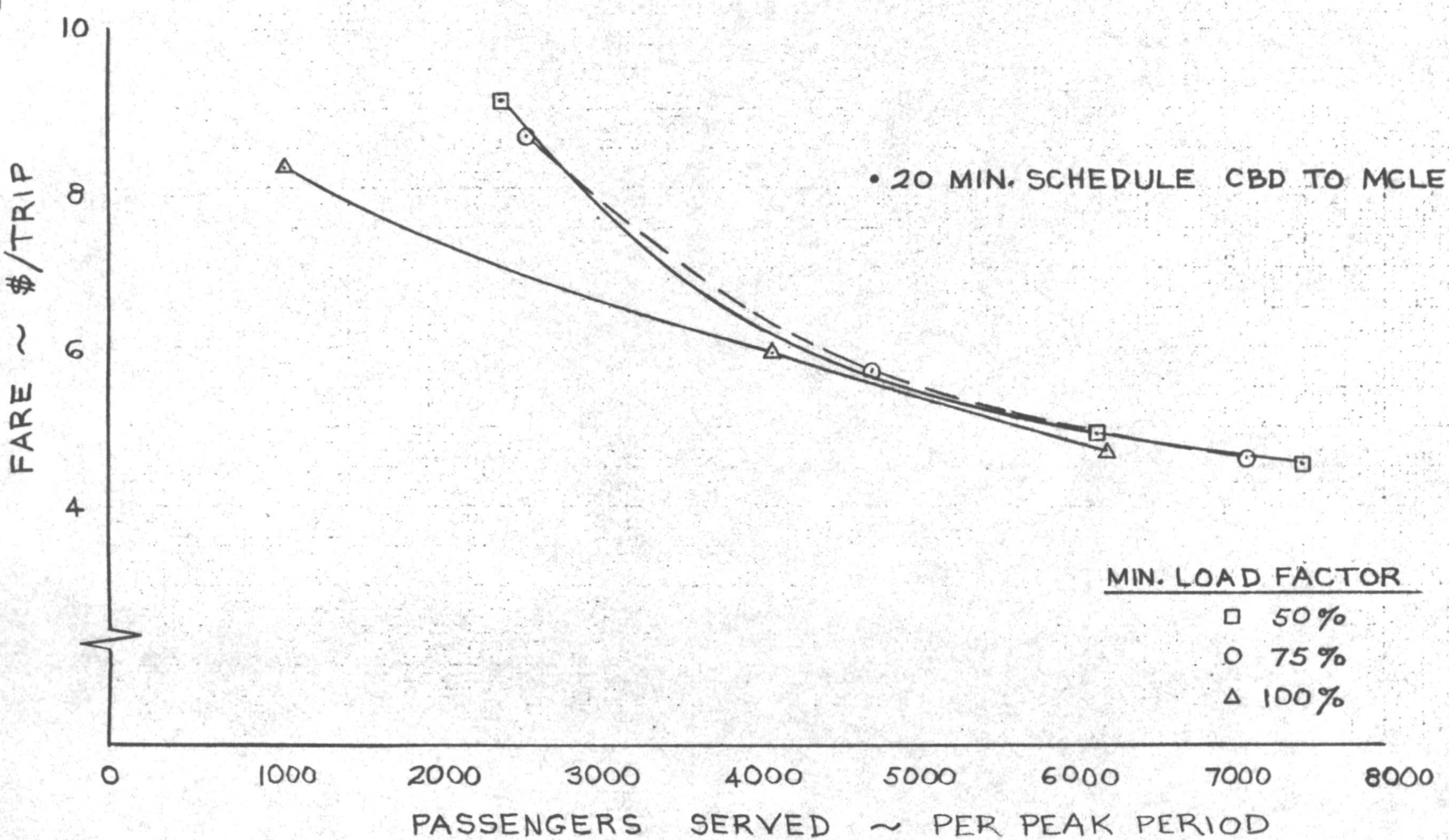


Figure 1.3-41 20-Minute Schedule Effect on the 1985 Tilt Wing VTOL

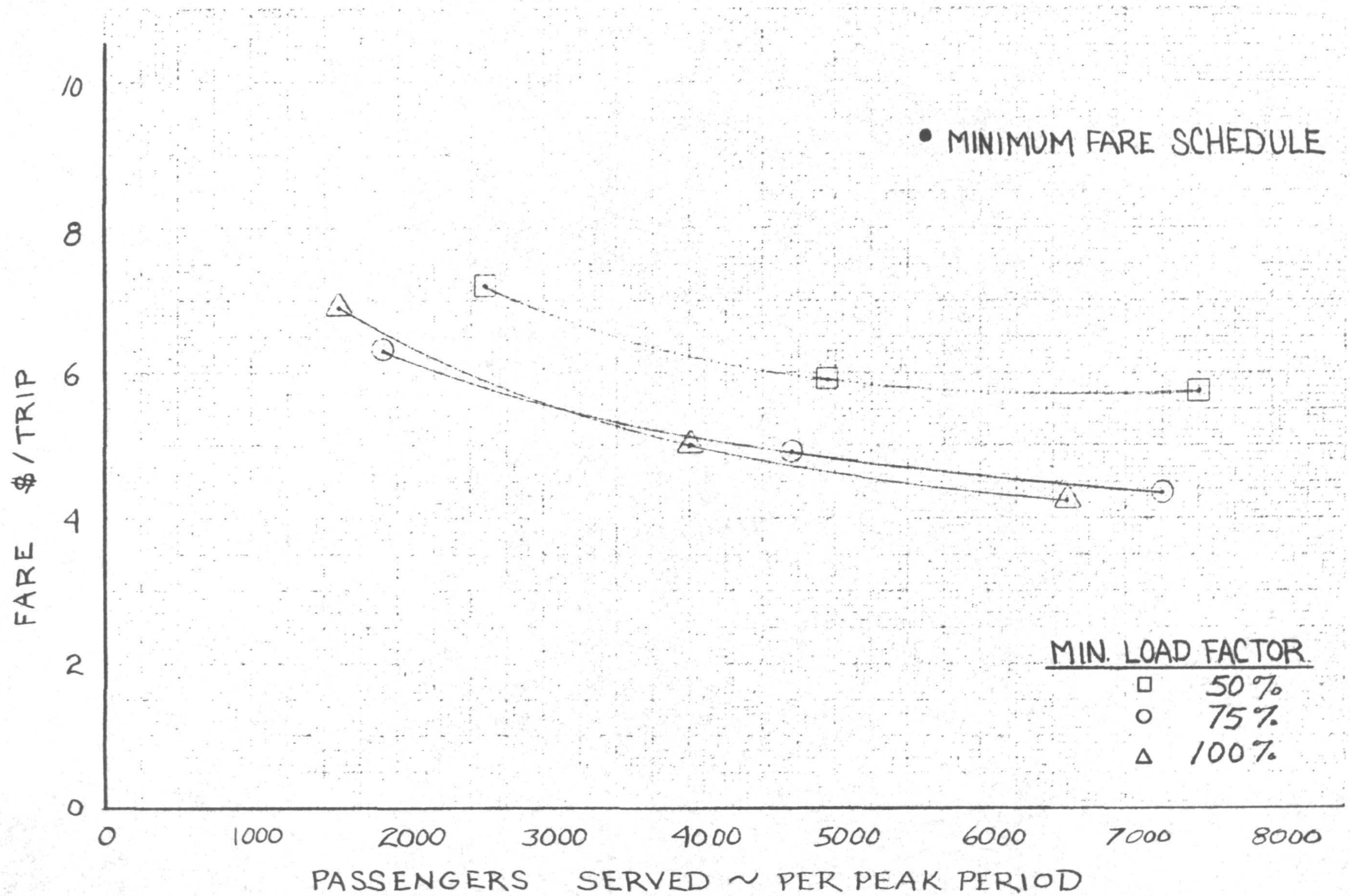


Figure 1.3-42 Minimum Fare Effect on the 1985 VTOL Compound Helicopter

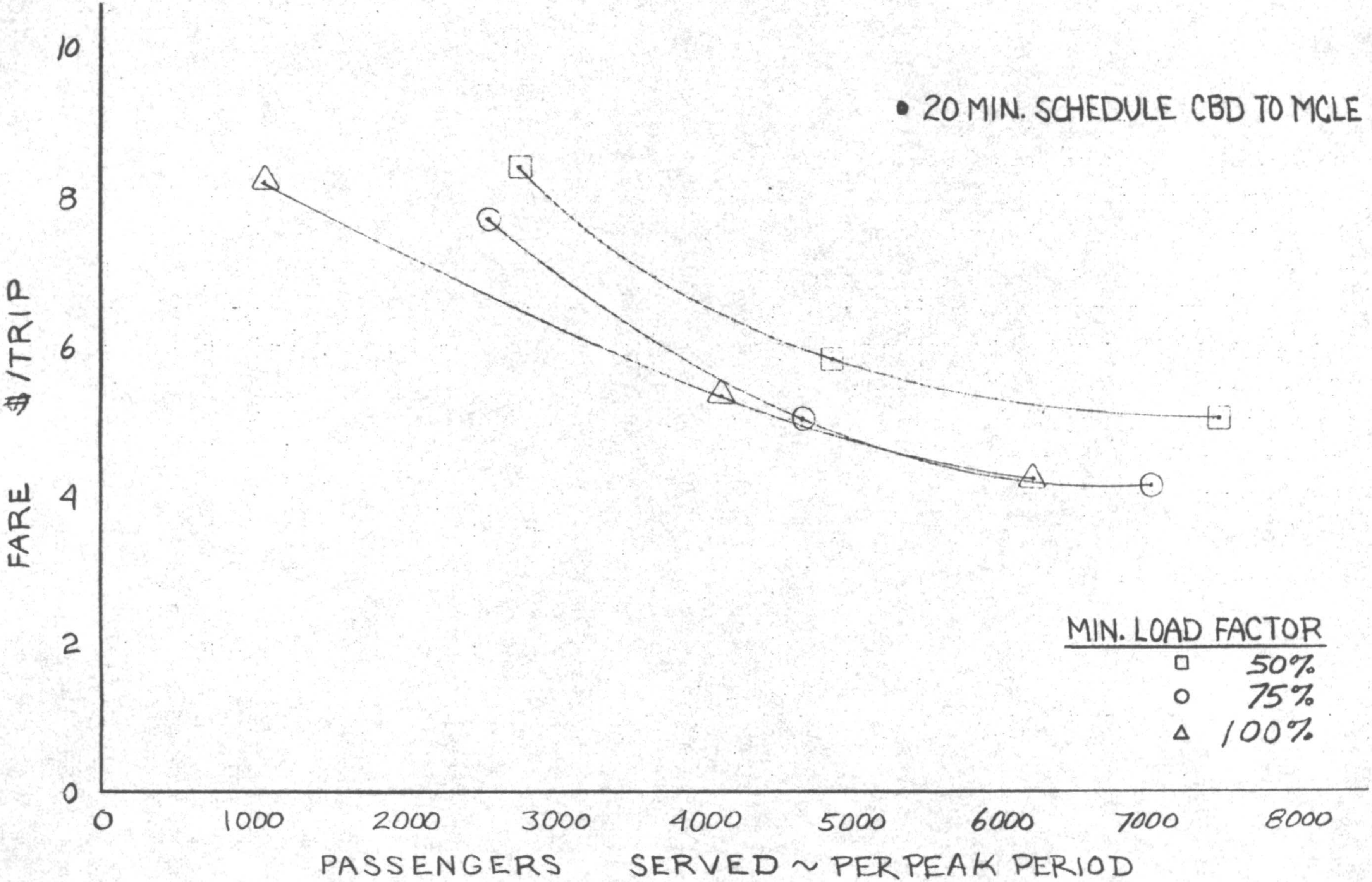


Figure 1.3-43 20-Minute Schedule Effect on the 1985 VTOL Compound Helicopter

1.3.1.5 Sensitivity Analysis

In order that the results of the subject study will have general applicability to other scenarios, Lockheed determined the sensitivities of the candidate aircraft concept systems to variations in five of the market and operational parameters: demand, minimum load factor, number of shifts, subsidy plans, and land values. The base point for each concept from which the parameter values were varied was 20 percent demand, 75 percent minimum load factor, 3 shifts, no subsidy, and the land values as presented in Table 1.1-31. The results of this analysis are presented in Table 1.3-10. This table shows the percent change in total system cost and fare for various changes from the base data noted.

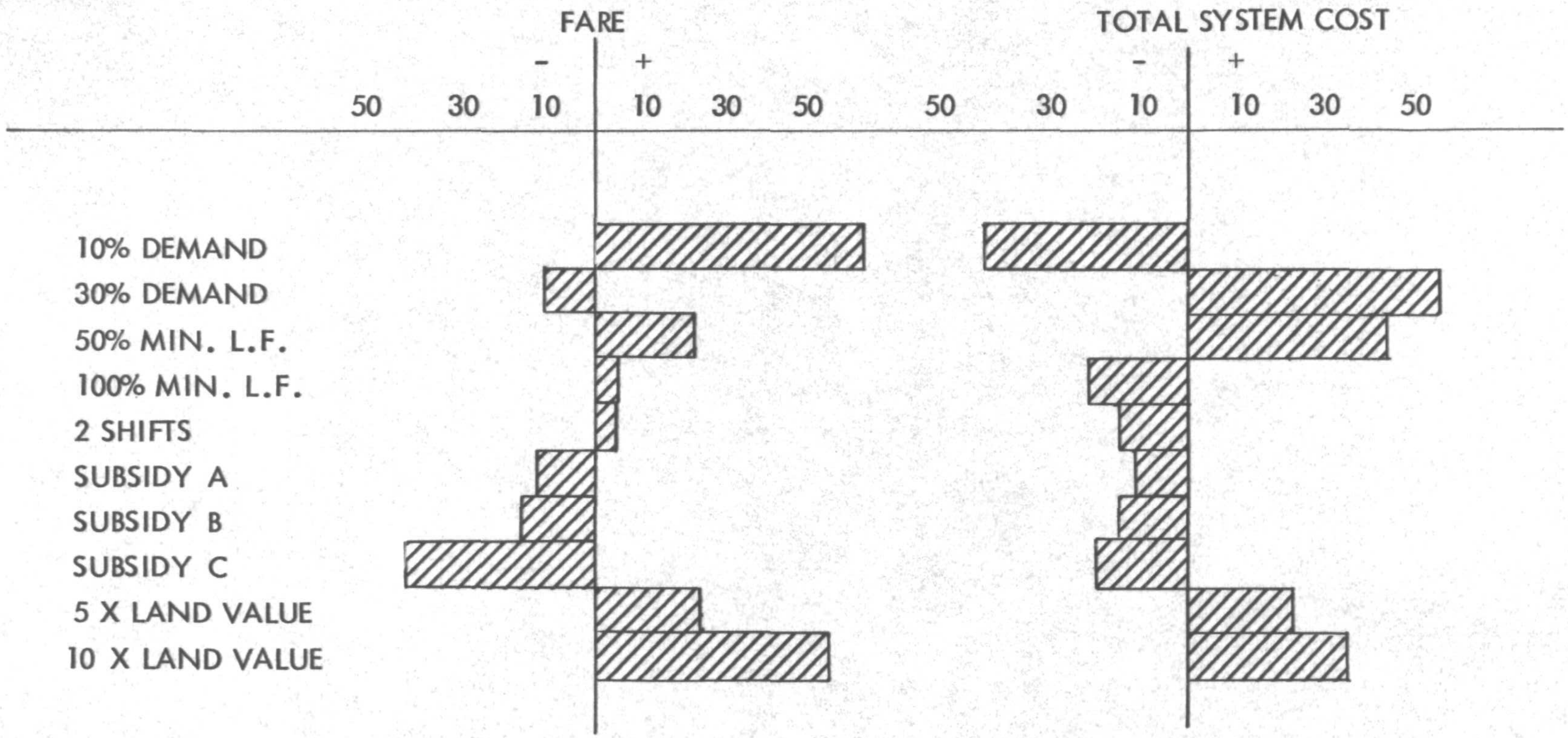
Some of the parameters have not been evaluated for the helicopter and the autogyro, but the percent change in these will be consistent with the change noted for the Tilt Wing Aircraft.

The sensitivities to variations in the market and operational parameters are consistent among the candidate concepts within each of the selected categories (1975 STOL, 1975 VTOL, 1985 STOL, and 1985 VTOL), and present no significant differences upon which to base a selection. This consistency, however, is significant in itself, and, along with the small (insignificant) variations in TSC and fare among concepts (per scenario), suggests that the final selection will be based on such factors as noise, comfort, convenience, and safety.

Another method of illustrating the sensitivity of cost to variations in market and operational parameters is displayed in Figure 1.3-44. This bar chart is a depiction of the cost sensitivity, to the changes noted, for the 1975 deflected slipstream airplane. Since the trends for all airplanes, in the fixed wing class, are the same, this example is considered representative for all aircraft except the helicopter, autogyro and tilt wing. Although not all of the sensitivities have been conducted on the rotary wing and tilt wing aircraft, those that have indicate a consistent pattern as is shown for the fixed wing, and the bar chart is used as back up for the discussion of the various parameters.

TABLE 1.3-10. SENSITIVITY ANALYSIS RESULTS

	1975 COMPOUND HELICOPTER	1985 COMPOUND HELICOPTER	1975 TILT WING	1985 TILT WING	1975 DEFLECTED SLIPSTREAM	1985 DEFLECTED SLIPSTREAM	1985 AUGMENTOR WING	1975 CTOL	1985 CTOL	1985 AUTOGYRO
BASE DATA:										
DEMAND	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
PASS CAPACITY	60	60	60	60	60	60	60	60	60	60
MIN LOAD FACTOR	75%	75%	75%	75%	75%	75%	75%	75%	75%	75%
FIELD LENGTH	150	150	150	150	1500	1500	1500	2500	2500	2000
TSC	242	319	282	355	240	310	371	247	327	323
FARE	5.04	4.83	5.9	5.4	5.01	4.70	5.6	5.15	4.95	4.88
TSC SENSITIVITY DATA (% CHANGE)										
10% DEMAND	- 50.4	- 55.0	- 52.9	- 54.9	- 46.7	- 52.3	- 53.9	- 44.2	- 51.1	- 50.5
30% DEMAND	+ 58.3	+ 53.0	+ 61.3	+ 54.1	+ 54.2	+ 50.0	+ 51.9	+ 51.4	+ 48.6	+ 47.8
50% MIN L.F.	+ 49.2	+ 40.4	+ 53.5	+ 42.5	+ 44.6	+ 36.8	+ 40.8	+ 42.1	+ 36.1	+ 35.4
100% MIN L.F	- 24.0	- 26.6	- 25.2	- 27.0	- 22.1	- 24.8	- 26.2	- 21.0	- 24.2	- 24.0
2 SHIFTS			- 15.9	- 14.9	- 16.3	- 14.5	- 14.6	- 15.4	- 16.2	
SUBSIDY A			- 5.7	- 5.6	- 12.5	- 10.3	- 9.2	- 16.2	- 15.0	
SUBSIDY B			- 7.5	- 7.3	- 14.2	- 12.6	- 10.8	- 17.8	- 16.8	
SUBSIDY C			- 3.5	- 3.9	- 20.8	- 2.3	- 3.0	- 2.0	- 3.7	
5X LAND VALUE			+ 4.6	+ 4.2	+ 22.9	+ 19.4	+ 15.4	+ 35.2	+ 25.4	
10X LAND VALUE			+ 6.4	+ 9.6	+ 35.8	+ 42.2	+ 34.8	+ 78.6	+ 59.4	
FARE SENSITIVITY DATA (% CHANGE)										
10% DEMAND	+ 48.6	+ 30.0	+ 40.7	+ 27.8	+ 59.9	+ 37.5	+ 31.1	+ 67.0	+ 40.9	+ 38.2
30% DEMAND	- 7.9	- 5.8	- 6.4	- 5.6	- 10.6	- 7.5	- 7.1	- 12.2	- 8.5	- 8.0
50% MIN L.F.	+ 26.4	+ 27.4	+ 28.8	+ 29.7	+ 22.4	+ 24.1	+ 28.6	+ 20.2	+ 23.4	+ 24.4
100% MIN L.F.	+ 3.8	+ 1.2	+ 1.7	0	+ 6.2	+ 3.4	+ 1.8	+ 7.8	+ 4.5	+ 3.7
2 SHIFTS			+ 5.1	+ 5.6	+ 4.4	+ 6.6	+ 7.1	+ 5.4	+ 4.9	
SUBSIDV A			- 6.8	- 5.6	- 12.2	- 10.6	- 8.9	- 16.3	- 14.9	
SUBSIDY B			- 8.5	- 7.4	- 14.4	- 12.6	- 10.7	- 17.9	- 16.8	
SUBSIDY C			- 37.3	- 40.8	- 42.4	- 45.1	- 37.6	- 40.8	- 44.0	
5X LAND VALUE			+ 3.4	+ 3.7	+ 22.8	+ 19.2	+ 16.1	+ 34.8	+ 25.5	
10X LAND VALUE			+ 10.2	+ 9.3	+ 51.1	+ 42.1	+ 35.7	+ 78.3	+ 59.5	



BASE POINT:

20% DEMAND
60 PASSENGER AIRCRAFT
75% MINIMUM L.F.
TSC $240 MILLION
FARE $5.0 PER PASSENGER

SENSITIVITY ANALYSIS

FIGURE 1.3-44. SENSITIVITY ANALYSIS

1.3.1.5.1 Demand

From the base value of 20 percent demand, Lockheed varied the demand projection ±50 percent to test the systems' sensitivity to demand variation (see Table 1.3-10.)

It is an important characteristic of the market scenario that a -50 percent variation in the demand capture projection results in a significantly greater decrease in actual demand served. This phenomenon is due to the loss of routes that (due to the 50 percent decrease in demand) will not support at least one flight. As a result, while the variation in TSC is approximately -50 percent, the variation in fare is approximately +50 percent because of the great loss of passengers served over which to amortize the cost of the system (see Figure 1.3-44).

A +50 percent variation in demand results in approximately a 50 percent increase in TSC, and approximately -10 percent decrease in fare. The decrease in fare in this case is due primarily to an increase in the efficiency with which the facilities are utilized. The cost for the aircraft is not a major portion of the total system cost, and although the number of aircraft are in direct proportion to the number of passengers the cost is not significant. The cost for facilities and their operating costs are a dominant cost and do not increase in direct proportion to number of passengers. They increase in the manner of a step function and fairly large increases in passenger numbers may be accommodated with very little additional cost. For example one passenger gate for an 80 passenger airplane with 75 percent load factor will handle from a minimum of 75 passengers to 2160 passengers during the peak 3 hour period, and at constant facility cost. Having the maximum number of passengers the gate will accommodate is the least cost per passenger.

1.3.1.5.2 Minimum Load Factor

For the purpose of the sensitivity analysis, minimum load factor was considered at 50, 75, and 100 percent (with 75 percent minimum load factor representing the base value). As expected, a change from 75 percent to 50 percent minimum load factor results in a significant increase in TSC

and fare due to increased aircraft and facilities requirements, and the small increase in passengers served over which to amortize the cost of the system. A change to 100 percent minimum load factor results in a significant decrease in TSC but an insignificant increase in fare due to the great loss of passengers served.

The comparison of variations in TSC and fare due to variations in minimum load factor are somewhat misleading. Of critical importance are the variations in the number of passengers served that result from the changes in minimum load factor. The results of this analysis are presented in Tables 1.3-11 and 1.3-12. It can be seen that increases in minimum load factor constraints produce a significant decrease (percent) in passengers served, and this effect is magnified as passenger capacity of the aircraft increases (due to loss of routes incapable of supporting at least one flight.)

1.3.1.5.3 Shifts

Because the facilities operations costs represent such a high percentage of the TSC, Lockheed investigated the possibility of operating the system over two shifts as opposed to three. This was accomplished by eliminating all flights between 1800 hrs and 0600 hrs. Although this change resulted in an approximately 16 percent decrease in TSC, fare was increased approximately 5 percent because the elimination of flight operations after 1800 hrs resulted in a 20 percent loss in passengers served. If a shift is eliminated without a loss in passengers served the fare is decreased by 15 percent or from $5.00 per passenger to $4.25.

1.3.1.5.4 Subsidy/Grant

The influence of subsidy or grants on total system cost and fare was investigated. The regulatory criteria established for airline operation does not apply to the intraurban transportation system and therefore certain assumptions were made. Three different assumptions were made in relation to the cost for facilities and development. These are listed below.

A. A grant is received for the purchase and maintenance of the passenger terminals but a landing fee is charged to the system operator.

TABLE 1.3-11 1975 PASSENGERS SERVED VS EXPECTED DEMAND

(PEAK HOURS PERIOD)

Passenger Capacity		40			60			80			100		
Minimum Load Factor		50	75	100	50	75	100	50	75	100	50	75	100
10% Demand	Expected Demand	1909	1909	1909	1909	1909	1909	1909	1909	1909	1909	1909	1909
	Passengers Served	1909	1655	1360	1740	1392	930	1607	1058	720	1334	832	500
	Percent Served	100	87	71	91	73	49	84	55	38	70	44	26
20% Demand	Expected Demand	4018	4018	4018	4018	4018	4018	4018	4018	4018	4018	4018	4018
	Passengers Served	4018	3920	3320	3996	3562	2820	3818	3282	2720	3596	3082	2100
	Percent Served	100	98	83	99	89	70	95	82	68	89	77	52
30% Demand	Expected Demand	6027	6027	6027	6027	6027	6027	6027	6027	6027	6027	6027	6027
	Passengers Served	6027	5946	5280	6027	5880	4980	5937	5620	4560	5994	5167	4200
	Percent Served	100	99	88	100	98	83	99	93	76	99	86	70

TABLE 1.3-12 1985 PASSENGERS SERVED VS EXPECTED DEMAND

(PEAK HOURS PERIOD)

	Passenger Capacity	40			60			80			100		
	Minimum Load Factor	50	75	100	50	75	100	50	75	100	50	75	100
10% Demand	Expected Demand	2438	2438	2438	2438	2438	2438	2438	2438	2438	2438	2438	2438
	Passengers Served	2438	2240	1620	2281	1892	1500	2054	1769	960	1971	1151	700
	Percent Served	100	92	66	94	78	62	84	73	39	81	47	29
20% Demand	Expected Demand	5012	5012	5012	5012	5012	5012	5012	5012	5012	5012	5012	5012
	Passengers Served	5012	4910	4160	4990	4680	3840	4876	4480	3200	4784	4168	2900
	Percent Served	100	98	83	99	93	77	97	89	64	95	83	58
30% Demand	Expected Demand	7518	7518	7518	7518	7518	7518	7518	7518	7518	7518	7518	7518
	Passengers Served	7518	7452	6720	7518	7365	6240	7485	7085	6080	7485	7014	5600
	Percent Served	100	99	89	100	98	83	99	94	81	99	93	74.

B. A grant is received for only the purchase cost for the passenger terminals. The operator maintains the facilities and is not charged a landing fee for recouping the grant.

C. A grant is received for the system's share of the development cost for the aircraft and a general subsidy per passenger served.

Table 1.3-13 summarizes the results for the subsidy premises noted above. Subsidy A results in a $30 million decrease in total system cost with proportionate decrease in fare. Premise B gives approximately the same results as A. The maintenance cost for the facilities is offset by the $5.00 landing fee and the results are approximately the same. In subsidy C the total system cost is reduced by $5.0 million. This is the pro rata share for the development of the aircraft. The major reduction in fare is an allocation of subsidy of $2.00 per passenger served. For this particular demand and minimum load factor there are 4,604,840 passengers per year and the total cost of $2.00 per passenger plus the $5.0 million for development amounts to $9.63 million per year to bring the fare from $5.00 per passenger to $2.89.

1.3.1.5.5 Land Value

Because the Detroit land values (as provided by SEMCOG) appeared to be extremely low, Lockheed conducted a sensitivity analysis on this parameter by varying it by 5 times and 10 times the base value. The results of these changes are shown in Table 1.3-10 and Figure 1.3-44, and produce expected increases in both TSC and fare, varying in proportion to facility land requirements as related to takeoff field length requirements. The amount of land required is proportional to the runway area, the number of gates, and number of passengers. The demand is constant for this analysis and therefore the number of gates and number of passengers are also constant. This leaves the runway length as a variable and its effect with changes in land cost may be noted. As an example, it may be noted from the information on Table 1.3-10 that for five times the land cost the total system cost for the deflected slipstream aircraft (1975) increases approximately 23 percent

TABLE 1.3-13. SUBSIDY COMPARISON - 1975 DEFLECTED SLIPSTREAM

75% MIN. L.F., 60 PASSENGER, 20% DEMAND

SUBSIDY	TOTAL SYSTEM COST ($ - MILLIONS)		FARE ($ PER PASSENGER)		COST PER YEAR FOR SUBSIDY ($ - MILLIONS/YEAR)
	WITHOUT SUBSIDY	WITH SUBSIDY	WITHOUT SUBSIDY	WITH SUBSIDY	
A	240	210	5.01	4.38	2.50
B	240	206	5.01	4.29	2.83
C	240	235	5.01	2.89	9.63

with a corresponding increase in fare of 23 percent. The increase in cost for the tilt wing aircraft is approximately 5 percent for TSC and 3.5 percent for fare. The land costs for the Detroit area do not approach the land costs for other areas such as downtown New York, Chicago, San Francisco and Los Angeles, and therefore does not penalize the CTOL aircraft to a major degree. This is noted in Figure 1.3-15 where it is shown that the total facility and equipment cost, including land is only a small portion of the total system cost.

1.3.1.5.6 Fare Versus Flight Schedule

The fare and schedule relationship is a culmination of the data for the deflected slipstream aircraft for the 1500 foot field length, and 75 percent minimum load factor. The fare and schedule relationship for this airplane, as shown in Figure 1.3-45, is typical for all aircraft; the difference between concepts would be noted by a slight shifting of the carpet plot to the right or left.

The purpose of this plot is to show that to obtain a reasonable fare and schedule there must be a daily passenger volume of approximately 25,000 people. This corresponds to the 30 percent demand level for the 1975 time period. If a $4.00 fare and a 20 minute schedule is desired then a daily traffic volume of approximately 30,000 people would be required and the airplane would be of 80 passenger capacity. If the demand is considered as fixed at a constant volume then an aircraft size may be chosen to minimize the time between flight and fare. If the daily traffic volume between the Central Business District (CBD) and Mount Clemens (MCLE) is determined to be 20,000 people one could choose an airplane of approximately 60 passenger capacity to strike a compromise between fare and schedule. The schedule may be minimized to 10 minutes if the daily traffic volume of 25,000 persons are transported by a 40 passenger airplane. This could be accomplished at a fare of $5.35, but poses the question as to whether this many people would pay the $5.35 fare for this distance. If minimum time between flights is the primary objective but people would not pay the fare to support the system then the alternative is adding a subsidy to lower the fare to the point where it would be acceptable.

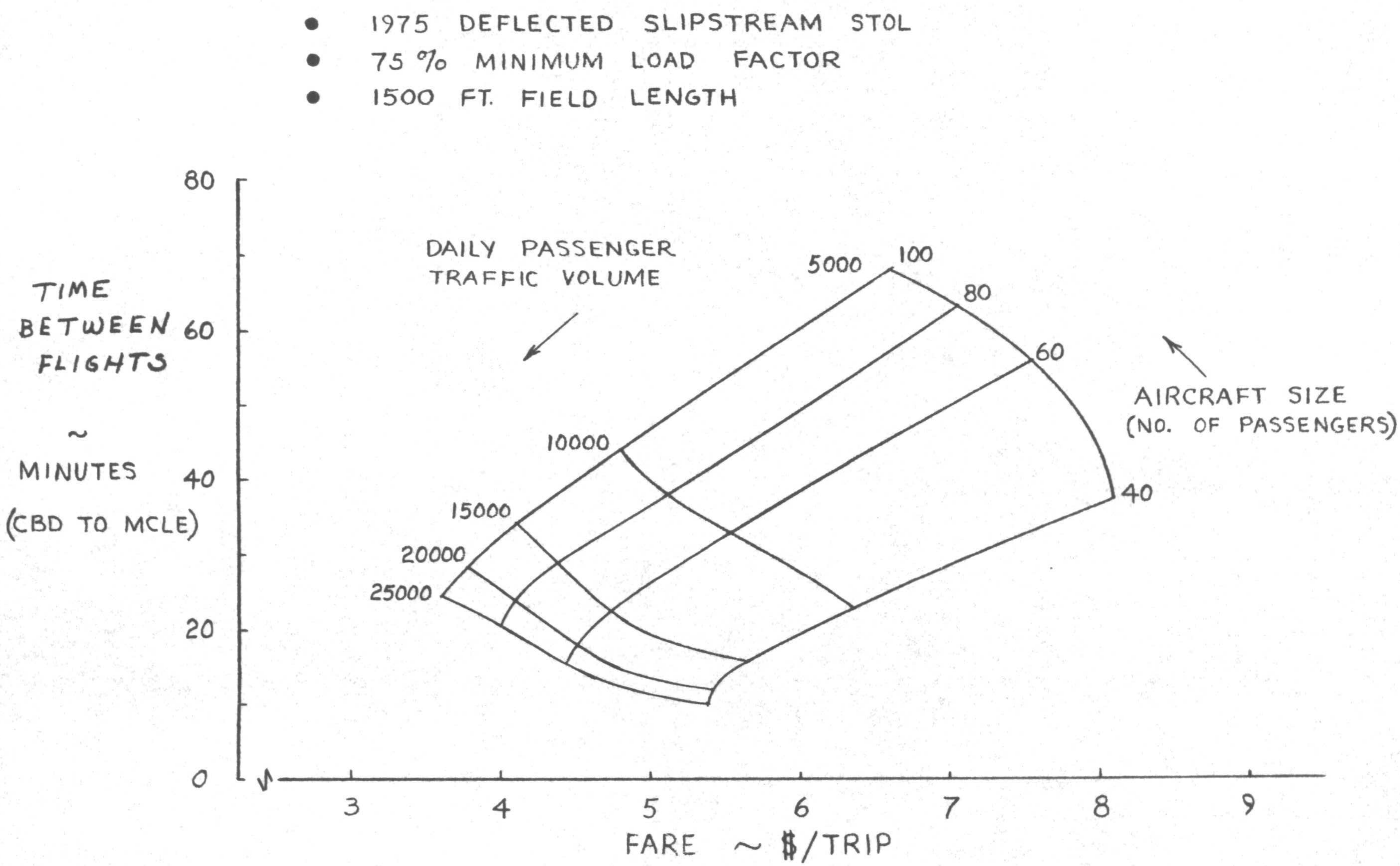


FIGURE 1.3-45. FARE $/TRIP

1.3.2 ADVANCED TECHNOLOGY IMPACT

The cost impact of anticipated 1985 technology advances in each of the cost sensitive technology areas shown in Section 1.1.2 for appropriate fixed wing concepts has been evaluated. In exercising these concepts through the matrix of technologies (i.e., aerodynamics, propulsion, structures, etc.), the sensitivities of each major technology discipline was determined separately in order to determine the most critical areas where the largest potential payoff exists. The results are summarized in Figure 1.3-46 and discussed below. Values are appropriate to a near optimum configuration (payload, W/S, T/W) for each concept. A corresponding analysis for the point design rotary wing concepts has not been conducted. However, the cumulative technology gains for these concepts are shown in Figure 1.3-47.

1.3.2.1 Aerodynamics

Advances in fixed wing aerodynamics are largely limited to gains in circulation lift capacity and the resulting reduction in takeoff and landing distances, primarily for the CTOL concept. This technology gain reduces the CTOL and STOL field lengths by four and two percent, respectively, with a corresponding reduction in flyaway, DOC and total system cost. No attempt is made to improve cruise L/D by aerodynamic refinements since potential gains would be at the expense of increased weight and manufacturing costs, and would likely affect total cost adversely.

1.3.2.2 Propulsion

The 1985 propulsion technology shows a large reduction in gross weight for the high T/W tilt wing VTOL due to reduce engine weight and improved specific fuel consumption. Corresponding reductions in costs also occur.

The deflected slipstream STOL concept exhibits but a minor reduction in weight due to improvements in its turboprop engine; and not sufficient to overcome the associated adverse effects of the more sophisticated engine on development, construction and maintenance costs. Total costs are thus increased slightly.

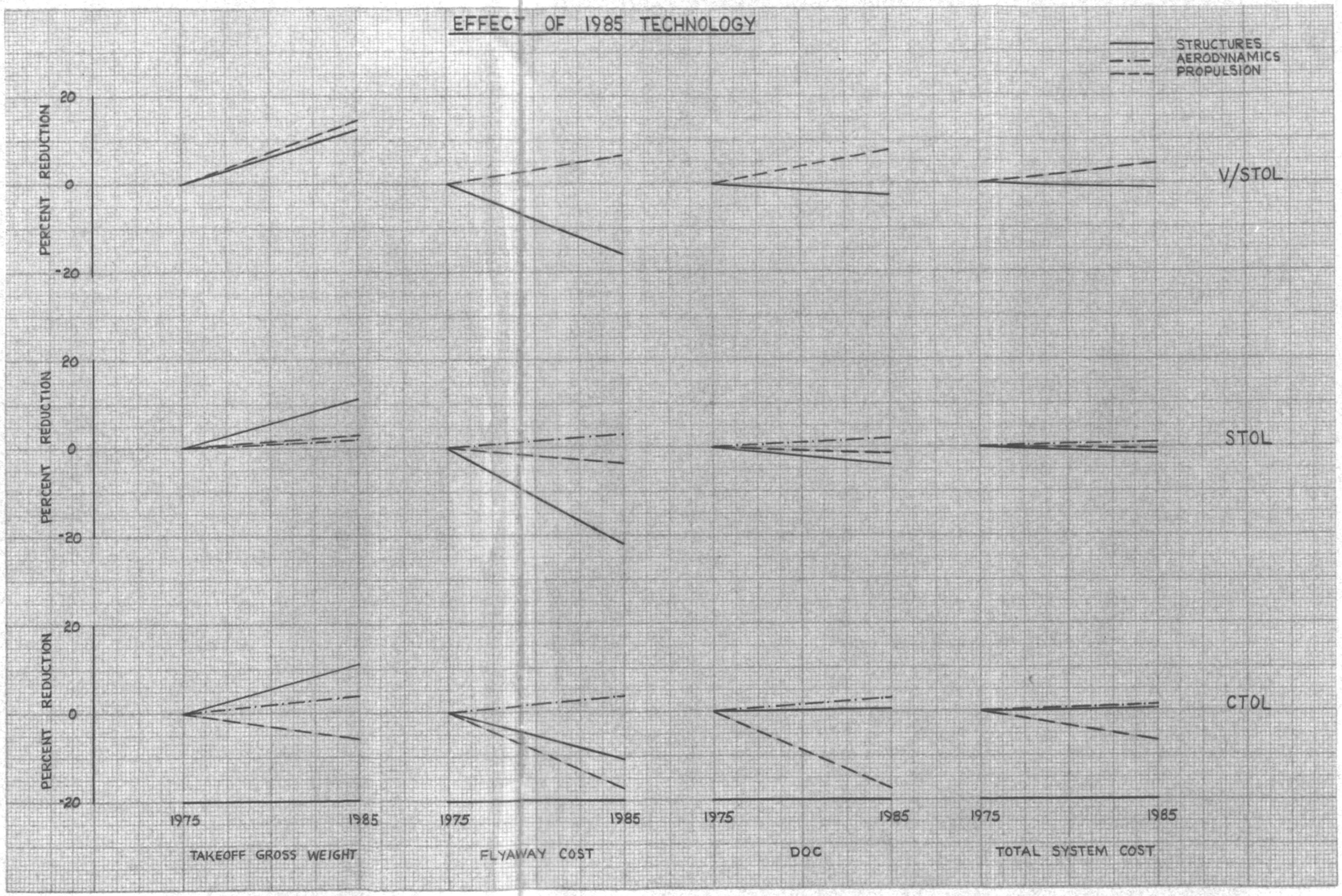


Figure 1.3-46 Effect of 1985 Technology

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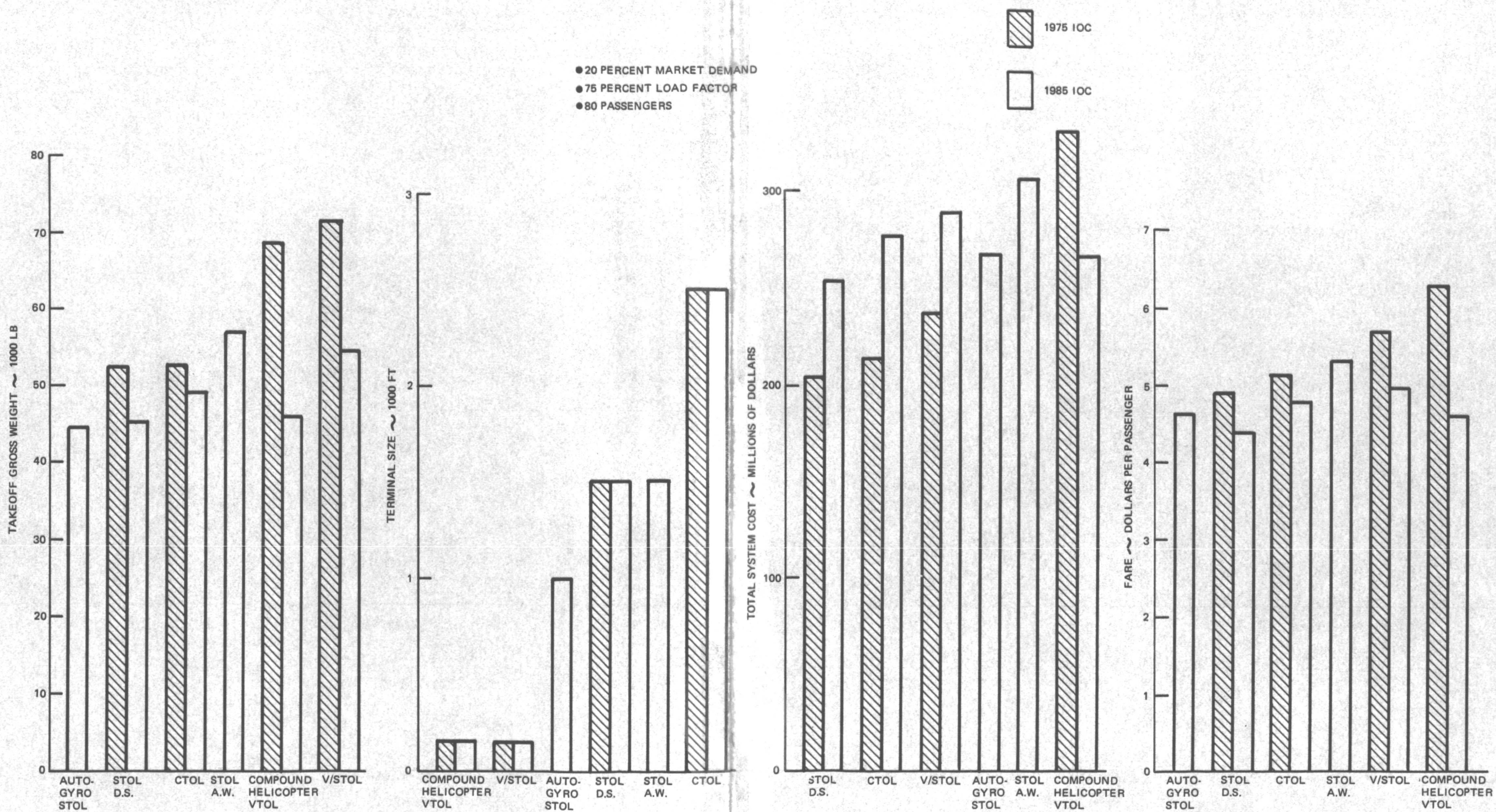

Figure 1.3-47 1975-1985 Technology Comparison

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Replacement of the 1975 CTOL turboprop propulsion system with the lighter, but more fuel-greedy 1985 turbofan engine causes an increase of six percent in gross weight. This in turn causes a large increase in cost; i.e., 17 percent in flyaway costs, 17 percent in DOC and 6 percent in total system cost.

1.3.2.3 Acoustics

No attempt has been made to assign a dollar value to the subjective benefits of the nominal 3-4 PNL noise reduction expected through technology by 1985. The greatest relative benefit here, however, should be for the tilt wing VTOL concept.

1.3.2.4 Structures/Materials

The use of advanced structures and materials in the fixed wing airframes and systems results in reducing their takeoff gross weights by 11 percent. However, the flyaway cost is penalized due to the expense involved in using the advanced materials. This effect is true for all three concepts. The tilt wing V/STOL shows a 16 percent flyaway cost penalty and a three percent DOC penalty using 1985 Structures/Materials Technology. The flyaway cost penalty on the deflected slipstream concept is even greater (22 percent) while it is reduced to 11 percent for the CTOL concept. This flyaway cost penalty is offset by the favorable effects of the reduced gross weights so that the resulting total system costs are not significantly affected.

1.3.2.5 Aircraft Systems

It is forecasted that technology advances will provide for substantial reductions in systems maintenance costs by 1985. However, quantitative information is lacking and this cost item is therefore left at its 1975 value.

1.3.2.6 Advanced Technology Comparison

Figure 1.3-46 shows the comparison of the 1975 IOC technology to that of using all 1985 IOC technology for each of the concepts as a function of takeoff gross weight, terminal size, total system cost and fare (summation of

all technologies). The data shown herein represent the 1975 IOC technology aircraft concepts superimposed on the 1975 passenger demand model and the 1985 IOC Technology Aircraft superimposed on the 1985 demand model.

Inspection of Figure 1.3-47 shows the following significant factors:

- All concepts show a substantial weight reduction with application of 1985 technology, with the VTOL concepts showing the greatest benefit.

- All concepts show increased total system cost through application of 1985 technology except the compound helicopter. This counter trend for the helicopter is heavily influenced by substitution of the pneumatic rotor drive system described in Section 1.1.

- All concepts show reduced fares for 1985 as a result of increased demand.

- For 1975 the lowest fare concept is the defected slipstream STOL; for 1985 the autogyro, deflected slipstream STOL and compound helicopter concepts show about equally minimal values.

1.4 EVALUATION AND SELECTION

Determination of the optimum concepts for detailed analysis during Phase II is based on the cost analysis as well as several more subjective factors. These are as follows:

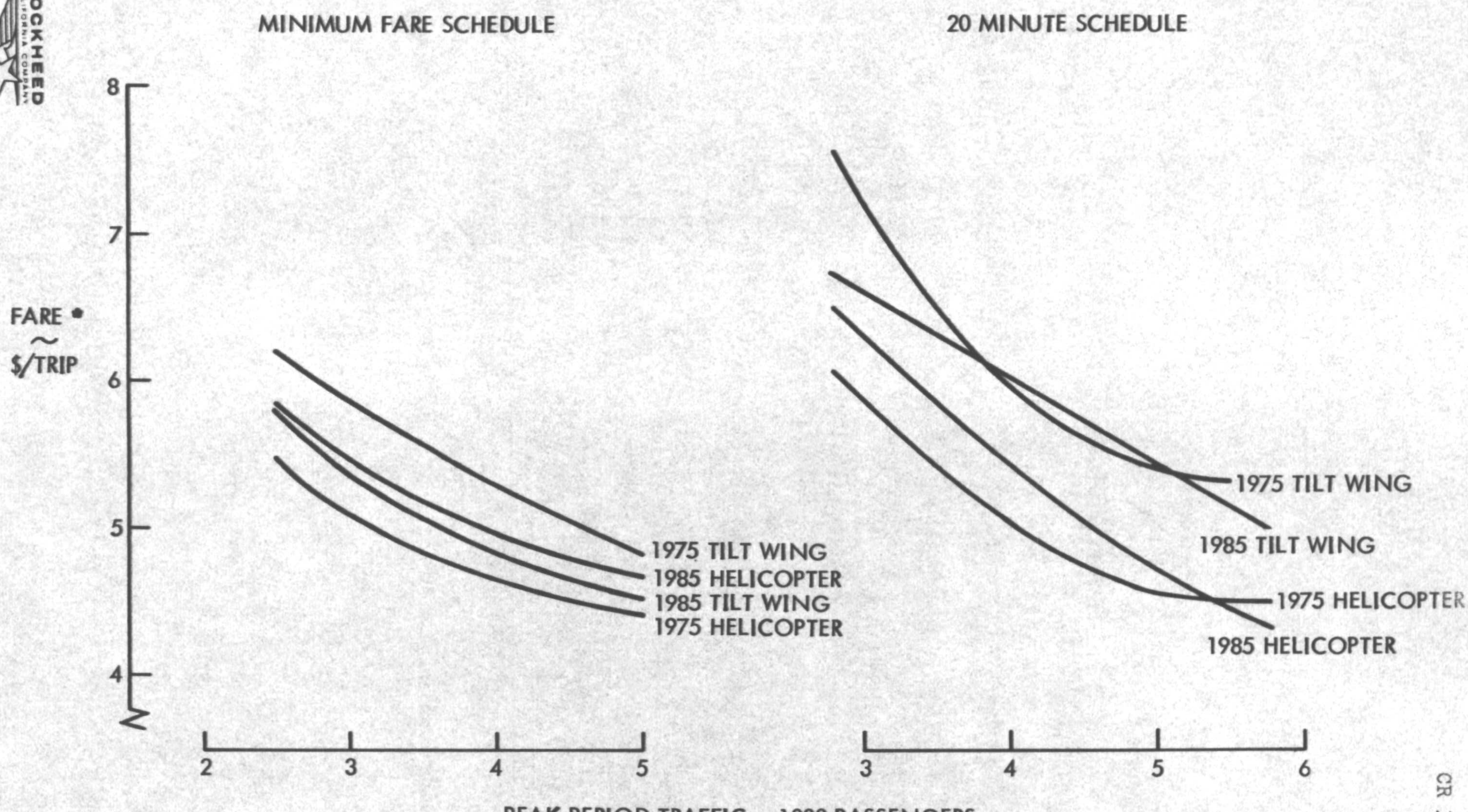
- Cost/Fare Analysis - Total system costs, as reflected in the required fare for the VTOL and STOL categories are shown in Figure 1.4-1 and 1.4-2 for each concept considered. Both minimum fare and 20 minute schedule values are shown. Inspection of these data shows that the spread in required fare varies significantly with aircraft concept, particularly for the STOL category. For the VTOL class, the helicopter is clearly the lowest fare concept. For the STOL category the deflected slipstream concept shows the lowest fare in the minimum fare analysis, while the lowest fare concept changes from CTOL in 1975 to STOL in 1985 for the 20 minute schedule analysis. From costs considerations, it is therefore judged that the preferred concepts are the compound helicopter VTOL and the deflected slipstream STOL.

- Utility - All concepts have been specifically designed to the intra-urban mission and thus have roughly the same utility within these design limits. Growth potential of all concepts is likewise considered to be about the same.

- Technical Risk - The 1975 concepts are all considered to be "low risk." The 1985 VTOL's and the deflected slipstream STOL and CTOL concepts are likewise considered "low risk." The augmentor wing and autogyro STOL concepts, from this point in time, are considered to involve some risk; not feasibility risk, but rather, return on development risk, or development sensitivity.

- Operational Factors - The impact of new regulations and other operational factors associated with an airborne intraurban transportation system is judged to be about the same for all concepts.

- Passenger Appeal - It is judged that all concepts can be made equally safe. Passenger acceptance will, therefore be dominated by ride qualities, which in turn, are heavily influenced by wing loading and cruise speed. The high wing loading VTOL and powered STOL concepts are thus to be favored over the CTOL concepts which generally require lower wing loadings to provide short field length performance. Passenger cabin environmental comfort levels are the same for all concepts. Other passenger acceptance factors cannot be reasonably assessed at this point (five to fifteen years prior to service), suffice to say that the public is currently conditioned to fixed wing non-VTOL types and this is expected to continue for some years.



* NO SUBSIDY; 15% RETURN ON INVESTMENT

Figure 1.4-1 Comparison of VTOL Concepts

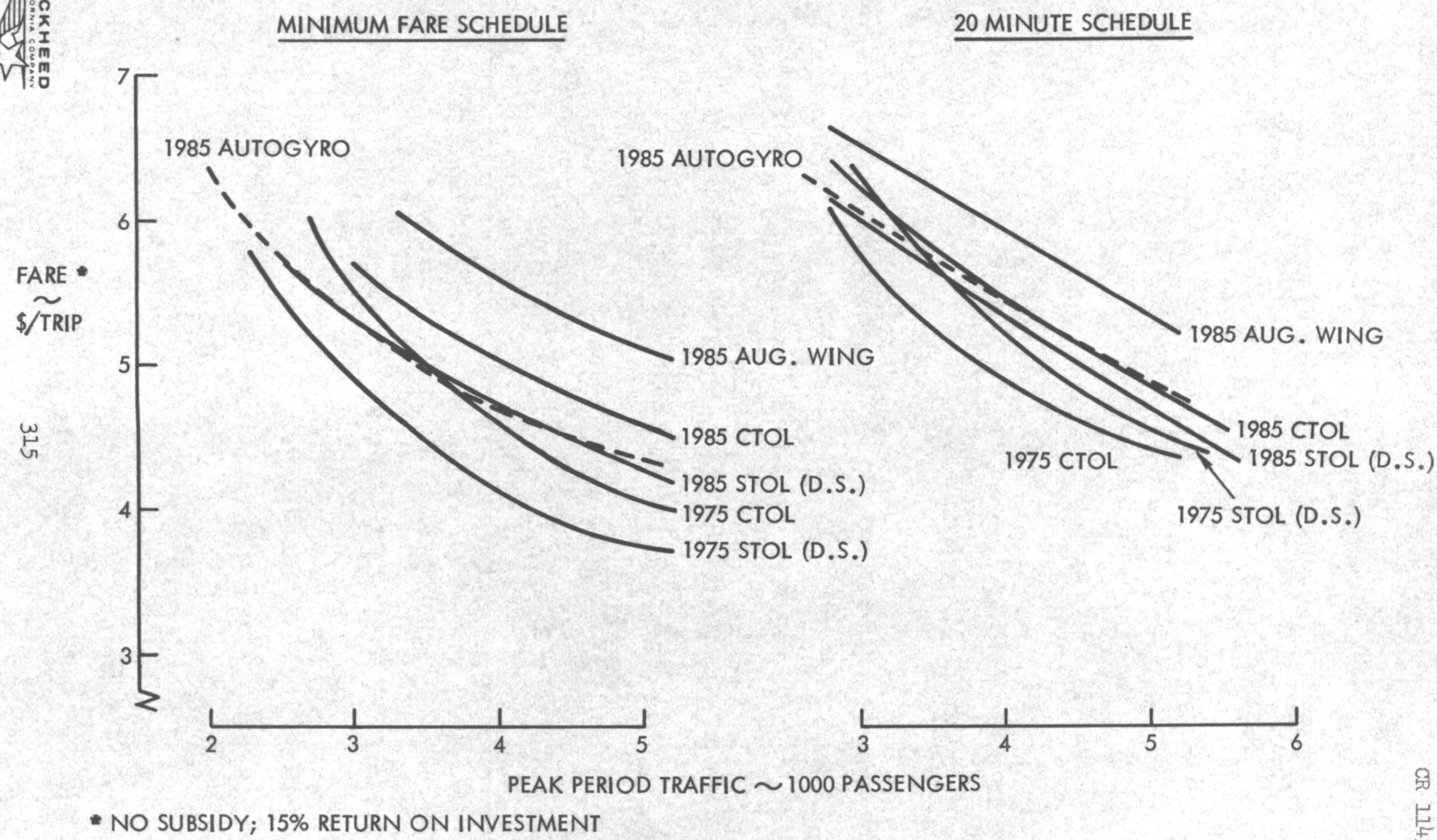


Figure 1.4-2 Comparison of STOL Concepts

- Community Acceptance - Community acceptance will be dominated by the system noise and the tilt wing VTOL concept is thus likely to be unacceptable here. Other concepts show significantly lower noise levels, with the deflected slipstream STOL being the lowest by an appreciable amount. A secondary factor will be airport in-out flight paths. Here, the VTOL's with their slow, steep flight paths should be favored.

A summary of the above remarks, along with the concept selection is presented in Table 1.4-1.

TABLE 1.4-1 CONCEPT SELECTION SUMMARY

Concept	Fare ~ $/Trip 20 Mile Service 1975	Fare ~ $/Trip 20 Mile Service 1985	Fare ~ $/Trip Min. Fare Schedule 1975	Fare ~ $/Trip Min. Fare Schedule 1985	Takeoff Noise Level PNL ~ PNdB 1000 FT Sideline 1975	Takeoff Noise Level PNL ~ PNdB 1000 FT Sideline 1985	Community Acceptance	Ride Qualities	Passenger Appeal	Tech. Risk	Selection 1975	Selection 1985
Comp. Heli-copter VTOL	5.40	5.30	5.20	5.00	90.2	87.7	Good	Good	Fair	Low	✓	✓
Tilt Wing VTOL	6.50	5.90	5.70	5.15	100.0	96.0	Poor	Good	Fair	Low		
Defl. Slip-stream STOL	5.40	4.90	5.30	4.46	86.0	83.0	Fair/Good	Fair/Good	Good	Low	✓	✓
Augmentor Wing STOL	-	5.80	-	5.35	-	91.7	Fair	Fair	Good	Medium	-	
Autogyro STOL	-	5.00	-	4.87	-	(1)	Fair/Good	Good	Fair	Medium	-	(2) ✓
Short Field Conventional	5.70	5.35	5.55	5.15	88.7	90.0	Fair/Good	Fair/Poor	Good	Low		

(1) Autogyro noise analysis still underway

(2) To be carried as non-contract parallel study.

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1.5 CONCLUSIONS AND RECOMMENDATIONS - PHASE I

- The Phase I Analysis indicates that Phase II should be carried out as initially outlined in the Lockheed Proposal.
- The 1985 Autogyro STOL is competitive with fixed wing concepts.
- Vehicle concepts for the Phase II Analysis should be -

  VTOL - Compound Helicopter

  STOL - Deflected Slipstream

  STOL - Autogyro (non-contract in-house study)

- Community noise levels are shown to be a potential adverse factor in community acceptance of an airborne intraurban transportation system. Therefore, increase depth of analysis in Phase II.
- Advanced technology offers minimal benefits in airborne intraurban transportation scenario.
- STOL total system costs are relatively insensitive to design runway length, due to relatively low land costs in the Detroit area.
- Aircraft maintenance is a key factor in total system cost. Therefore, increase study depth in Phase II.
- STOLport maintenance is a key factor in total system cost. Therefore, increase in depth in Phase II.
- Ranking of vehicles is not affected by sensitivity analysis of system operational factors.
- Required fares, schedule frequency, and optimum design payload vary grossly with traffic volume. Accurate demand forecasts are therefore essential for a sound appraisal of potential of the airborne intra-urban transportation system.